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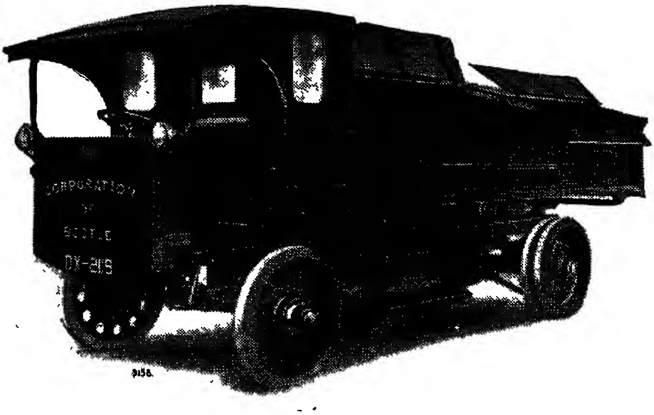

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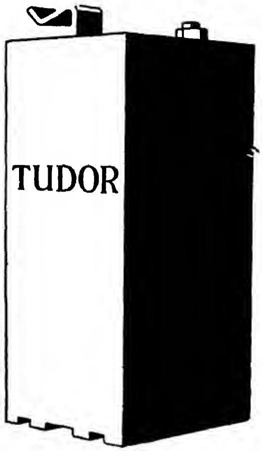

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ELECTRIC VEHICLES

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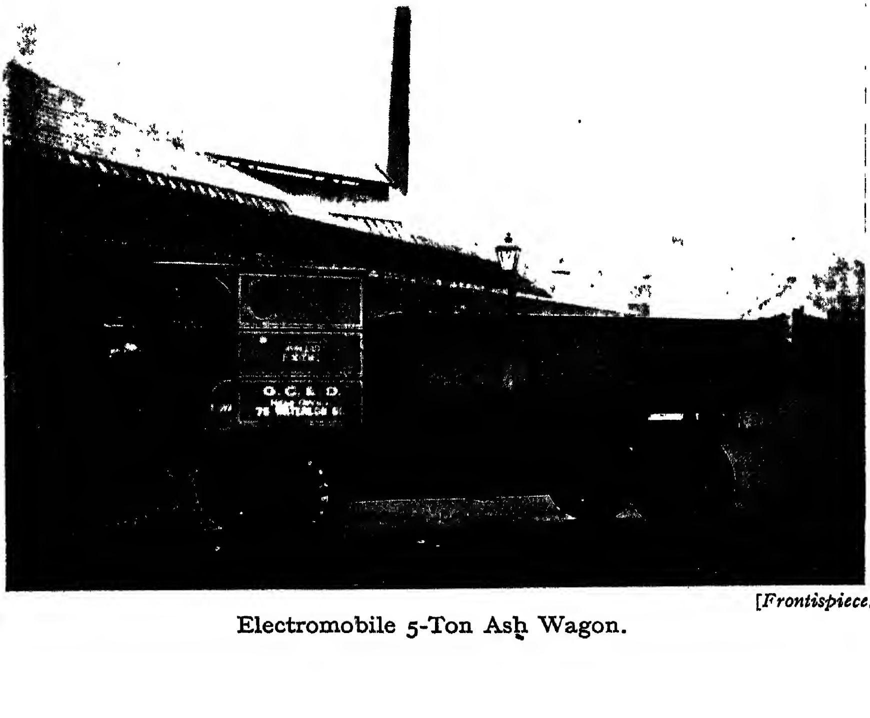

[*Frontispiece.*

Electromobile 5-Ton Ash Wagon.

ELECTRIC VEHICLES

BY

CHARLES W. MARSHALL,
B.Sc., A.M.I.E.E.

LONDON
CHAPMAN & HALL, LTD.,
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AUTHOR'S PREFACE

ELECTRIC battery vehicles have hitherto played a relatively unimportant part in the transport work of Great Britain, but at the present time they seem to have obtained a firm footing, and many engineers who formerly did not give them a thought are now considering them seriously, as competitors with other forms of transport. The early work done in Britain about twenty to thirty years ago has left very little impression on electric design, and the standard types of vehicles now in use have their origin in American practice. This is largely due to the fact that, whereas there was a long period of almost complete stagnation in this country, American engineers never wholly relinquished their efforts to produce a sound battery vehicle. In this book the author endeavours to give a general account of the fundamental principles underlying electric vehicle practice, and he hopes that it will be of use to present and prospective owners of electric vehicles, and, at least, of interest to designers and manufacturers.

Practically the whole of the author's experience has been gained while maintaining the vehicles of the Glasgow Corporation Electricity Department, and the courtesy of the Chief Engineer, Mr. R. B. Mitchell, in allowing the data obtained from his machines to be published, is gratefully acknowledged.

The author takes this opportunity of thanking the various manufacturers of vehicles and batteries who supplied him with particulars of their products.

C. W. M.

Glasgow,
March 1925.

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Messrs. Batteries, Ltd. (Figs. 18, 19).
Messrs. Chloride Electric Storage Co., Ltd. (Figs. 4, 5, 6, 7, 37).
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Messrs. Edison Accumulators, Ltd. (Figs. 14, 15, 16, 17).
Messrs. Electricars, Ltd. (Figs. 31, 32).
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Messrs. General Vehicle Co. (Figs. 20, 43).
Glasgow Corporation Electricity Dept. (Figs. 21, 21*a*, 30, 34, 36, 38, 41, 42).
Messrs. Igranic Electric Co., Ltd. (Fig. 35).
Messrs. Iron & Michel Battery Co., Ltd. (Figs. 19*d*, 19*e*).
Messrs. Philadelphia Battery Co. (Figs. 10, 11).
Messrs. Ransomes, Sims and Jeffries (Figs. 27, 28).
Messrs. Tudor Accumulator Co., Ltd. (Fig. 19*a*).
Messrs. Walker Electric Vehicle Co. (Figs. 22, 23).

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ELECTRIC VEHICLES

CHAPTER I

ENERGY AND POWER REQUIREMENTS FOR ROAD VEHICLES

In text-books and articles dealing with the subject of traction it is customary to use the horse-power-hour and the foot-pound as units of energy, and the horse-power as the unit of power. It is, however, very convenient when dealing with electric traction to use the kilowatt-hour and kilowatt. These units are largely used in the present book, and in order to make the relationships between the two systems quite clear the connecting formulæ are summarised below.

Units of Energy.—1 Kilowatt hour = 2,660,000 or $2{\cdot}66 \times 10^6$ foot-lbs. = 1·341 horse-power-hours.

Units of Power.—1 Kilowatt = 1·341 horse-power = 738 foot-lbs. per second.

The principal advantage of using the kilowatt and kilowatt-hour as standard units lies in the fact that they are very easily and accurately measured in battery vehicle working.

The total amount of energy which has to be expended in moving any kind of road vehicle steadily from one point to another may be subdivided into four principal components. These are :—

(1) The energy required to overcome the force of gravity,
(2) ,, ,, ,, ,, road resistance,
(3) ,, ,, ,, ,, air resistance,
(4) ,, ,, ,, ,, frictional resistances in the mechanism of the vehicle.

The relative values of the different components vary very widely, so that each source of loss must be considered separately.

Resistance due to Gravity.—The first component is the only one which admits of exact calculation. The energy expended is obtained directly from the product of the total weight of vehicle, and the vertical distance traversed. Thus on a gradient of one in ten, the minimum energy expenditure per ton per mile of route is $1{\cdot}1_8 \times 10^6$ foot $\times$ lbs. or 0·45 kw.h. The miminum power at a speed of 10 miles per hour on this gradient would be approximately 6 horse-power or 4·5 kw.

Road Resistance.—Road resistance is now receiving close study, but no generally accepted tables of resistances for varying classes of road surfaces and types of tyres have yet been published. The total road resistance over a range of speed of from 10 to 15 miles per hour increases with the speed, and a few typical figures of values for surfaces ordinarily met with are given for illustration :—

Type of Road Surface.	Tractive Resistance.	
	Lbs. per Ton at 10 m.p.h.	Lbs. per Ton at 15 m.p.h.
Asphalt	19	21
Wood block	22	25
Granite setts	36	50

These figures are for vehicles working on solid rubber tyres of normal construction and thickness. It is claimed by some tyre-makers that their products are very much superior to others in respect to low energy consumption, but authentic data on this point are not so far available. Again, considering a definite example for illustration, it is found that with a road resistance of 40 lbs. per ton, the minimum energy consumption is $0{\cdot}21 \times 10^6$ foot $\times$ lbs. or $0{\cdot}07_9$ kw.h. per ton-mile on the level. The corresponding power is 1·07 h.p. or 0·79 kw. at a speed of 10 miles per hour.

Air Resistance.—The resistance to motion due to air may be calculated approximately from first principles by consideration of the change of momentum of the air caused by the passage of the vehicle. The principal factors entering into the calculation are the resisting area and the velocity of the air relative to this area. An empirical formula which covers a speed range of to 25 miles per hour has been published by the British National Physical Laboratory. This states that

$$F = 0{\cdot}0032\ Av^2$$

where F = resisting force in pounds,
A = area of resisting surface in square feet,
V = speed in miles per hour.

Taking a resisting area of 30 square feet, and a speed of 10 miles per hour as representative of average electric vehicle practice, it is found that the total resisting force is 9·6 lbs. The energy expenditure per mile is $0{\cdot}051 \times 10^6$ foot $\times$ lbs. or 0·019 kw.h., and at 10 miles per hour the power is 0·26 h.p. or 0·19 kw. for the complete vehicle.

The total energy requirements in the case considered are thus :—

				Kw.h. per ton mile.	
(1)	Energy to overcome		force of gravity . .	0·45	
(2)	,,	,,	road resistance . .	0·079	on total weight
(3)	,,	,,	air resistance . . .	0·007	(of 3 tons).
Total	,,	,,	forces external to veh.	0·536	

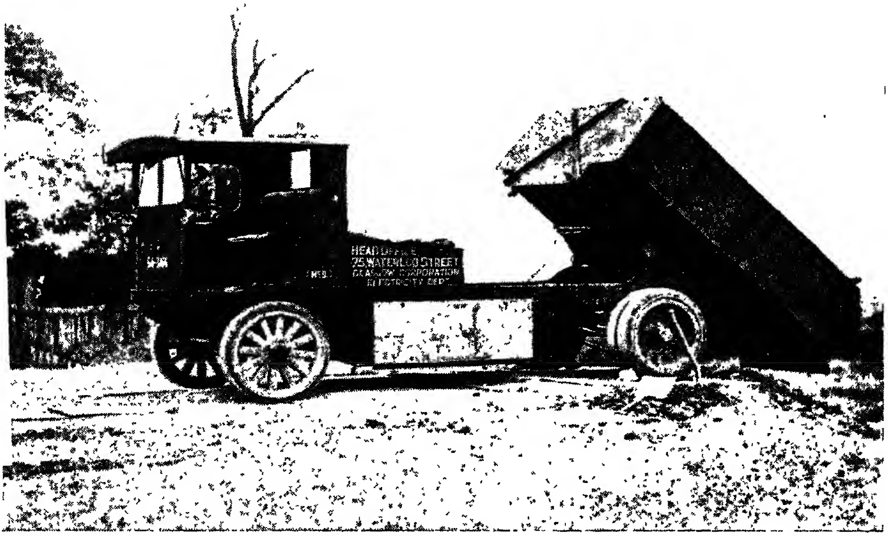
Energy losses in Vehicle Mechanism.—In this book only electric vehicles are considered, but the mechanical losses are similar in nature to those which occur in any machine. The separate parts of the total loss are not often considered, the usual practice being to state the overall efficiency of the whole power system. The efficiency obtained in ordinary designs in everyday use is about 80%. The motor alone has an efficiency at full load of about 85 to 90%. Spur gears give

about 96%, chain gears 95%, and worm gears 90%. These figures are given as illustrative of ordinary practice, but they cannot be much improved on under the best possible conditions. It follows, therefore, that an electric vehicle working up a gradient of one in ten at 10 miles per hour with a road resistance of 40 lbs. per ton in still air will require a battery output of $0{\cdot}536/0{\cdot}8 = 0{\cdot}67$ kw.h. per ton-mile. The battery efficiency, as will be seen later, cannot exceed about 75%, so that the total energy supplied to the vehicle in the above case must be not less than $0{\cdot}67/0{\cdot}75 = 0{\cdot}9$ kw.h. per ton-mile.

A further source of energy loss occurs in practice, due to the starting and stopping which are required. The minimum energy required to accelerate a vehicle of weight W lbs. from rest to a speed of V feet per second is $\frac{1}{2}\,\frac{W}{g}V^2$ foot × lbs. The energy required with $W = 2240$ lbs. and $V = 10$ m.p.h. $= 14{\cdot}7$ feet per second is 7600 foot × lbs., or $2{\cdot}85 \times 10^{-3}$ kw.h., that is, one kw.h. would accelerate one ton from zero to 10 miles per hour 350 times if there were no losses. In ordinary electric vehicle practice the efficiency during the starting period is only about 50%, so that this number would require to be halved to get the number of starts which would really be obtained. Many attempts have been made to recover the energy liberated during the decelerating period, but these have not been very successful, and the energy should be considered as wholly lost in making estimates of energy requirements.

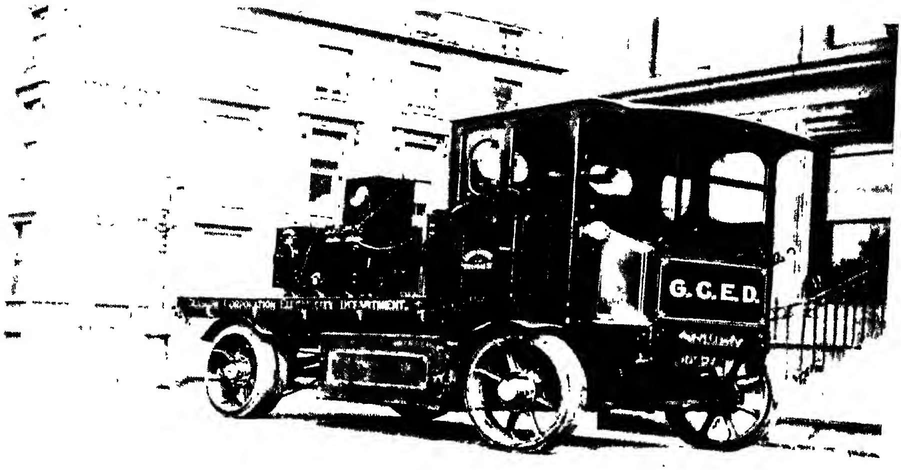
In everyday running on city delivery work, the author has found that the actual energy consumption of electric vehicles of different makes varies from 0·100 to 0·120 kw.h. per ton-mile. These figures were obtained on vans and lorries working exclusively in thick city traffic. The road surfaces were for the most part granite setts, so that, except in cases where the roads are exceptionally soft or rough, this energy consumption should represent the maximum to be expected from a well-constructed electric vehicle in good condition.

Walker 10-Ton Tractor.



Edison 5-Ton Ash Wagon.

[*To face page 4.*



Garrett 2½-Ton Lorry.

[To face page 5.

From the average figures of energy consumption, it is seen that a motor capacity of 1 kw. for each ton of gross weight of vehicle should be provided, as this is sufficient for maintaining an average speed of 10 miles per hour. The motor must, of course, have ample overload capacity to enable it to ascend the steepest gradient it can encounter. The nominal input rating of the motors of electric vehicles of from 2 to 5 ton load capacity is actually about 5 kw., the output in brake horse power being 5; the motors are, however, able to give three times the normal load for short periods.

The provision of energy storage is the main drawback of electric vehicles, and it is usually impossible to provide for more than about 30 miles per battery charge. To give this mileage, the battery capacity required is about 3 kw.h. per ton of gross weight of vehicle and battery. The minimum weight of the cells alone is 84 lbs. per kw.h. The significance of this figure is realised when it is compared with the energy storage capacity of petrol, which averages 19,000 B.Th.U.s per lb. or 0·18 lb. per kw.h. The great energy of petrol is very inefficiently utilised, even in the best vehicles, and this fact materially reduces the handicap against which electric vehicles must work, due to the excessive weights of all types of batteries as yet available.

The sizes of batteries required for the standard lorry capacities will now be calculated approximately. A plain platform lorry of 2-ton load capacity weighs approximately 12,080 lbs., or 5·4 tons complete with battery and load. The minimum energy consumption (battery output) is 0·1 kw.h. per gross ton-mile. The storage capacity required per mile is therefore 0·54 kw.h. For a distance of 30 miles per charge, the battery capacity must not be less than 16·2 kw.h. The standard lead battery voltage may be taken as 80 volts, so that the ampere-hour capacity required is 16,200/80 = 203. Similarly, the voltage of the usual Edison battery as fitted to electric vehicles is 60 volts, and the required ampere-hour

capacity is 16,200/60 = 270. Taking the other sizes of vehicle in the same way, we obtain the following table of minimum storage capacities.

Load Capacity.	Total Weight of Vehicle, Battery and Load.	Minimum Storage Capacity for 30 miles per Charge at 0·1 kw.h. per G.T.M.		
Tons.	Tons.	Kw.h.	A.h. Capacity at 80 Volts.	A.h. Capacity at 60 Volts.
½	2·42	7·26	91	121
1	3·45	10·35	129	173
2	5·4	16·20	203	270
3½	8·0	24·0	300	400
5	10·0	30·0	375	500

The battery capacities given above represent the lowest that should even be considered under the stated conditions.

In any special case they must be reviewed to meet the requirements of road surfaces, gradients, speed, and number of stops. It will also be found later in the chapter on batteries that the load on the battery, whether it be of the lead or Edison type, has a very great influence on its performance.

An example will now be worked to illustrate further the method of calculating power and energy requirements.

It is required to determine the power and energy per mile necessary to propel an electric vehicle over a given route, the data being as follows :—

Average Gradient, 1 in 100 (upwards).
Average Road Resistance, 30 lbs. per ton.
Wind, 10 m.p.h. (opposing motion of vehicle).
Total weight of Vehicle and Load, 5 tons.
" Opposing " Surface Area of Vehicle perpendicular to direction of motion, 30 ft.^{2}.
Average Speed, 10 miles per hour.
Average Overall Efficiency of Motor and Gearing, 80%.

The forces resisting the motion of the vehicle per ton are :—

		Lbs./ton.
(1)	Resistance due to gravity ($\frac{1}{100} \times 2240$)	= 22·4
(2)	,, ,, road friction	= 30
(3)	,, ,, air (20 m.p.h. Road velocity)	7·6
(4)	,, ,, vehicle losses, mechanical and electrical	15
	Total equivalent resistance	75

Energy required per ton-mile = 75×5280 = 396,000 foot-lbs. (and since 1 kw.h. = $2{\cdot}66 \times 10^6$ foot-lbs.) = 149 watt-hours. For the whole vehicle the energy per mile will be $0{\cdot}149 \times 5$ = 0·746 kw.h.

The time taken to traverse a mile is 1/10 hour, the average power is 7·46 kilowatts or 10 horse-power. The energy and power may be allocated proportionally to the respective resisting forces thus :—

	Kw.	H.p.	% of Total.
Rate of working against gravity . .	2·22	2·98	29·8
,, ,, ,, road friction .	2·98	4	40
,, ,, ,, air resistance .	0·76	1·02	10·2
,, ,, ,, vehicle losses .	1·49	2	20
Total	7·45	10	100

Table I.

Some Recently Published Data on Road Resistance.

Type of Surface.	Resistances in Pounds per Ton at 10 m.p.h.			
	Solid Tyres.		Pneumatic Tyres.	
	(a)	(b)	(c)	(d)
Asphalt	23	18·6	29	
Macadam	26·5	21	33·3	34–56
Tar macadam	26·2	23·5	33	Lower value
Wood block	24·6	22·3	31	for dry,
Granite block	46	36·2	58	higher for
"Melting snow" . . .	47·5	—	59·6	wet surface.

Generally in electric vehicle tests the total kilowatt-hours per vehicle mile, and the weight of the vehicle are determined.

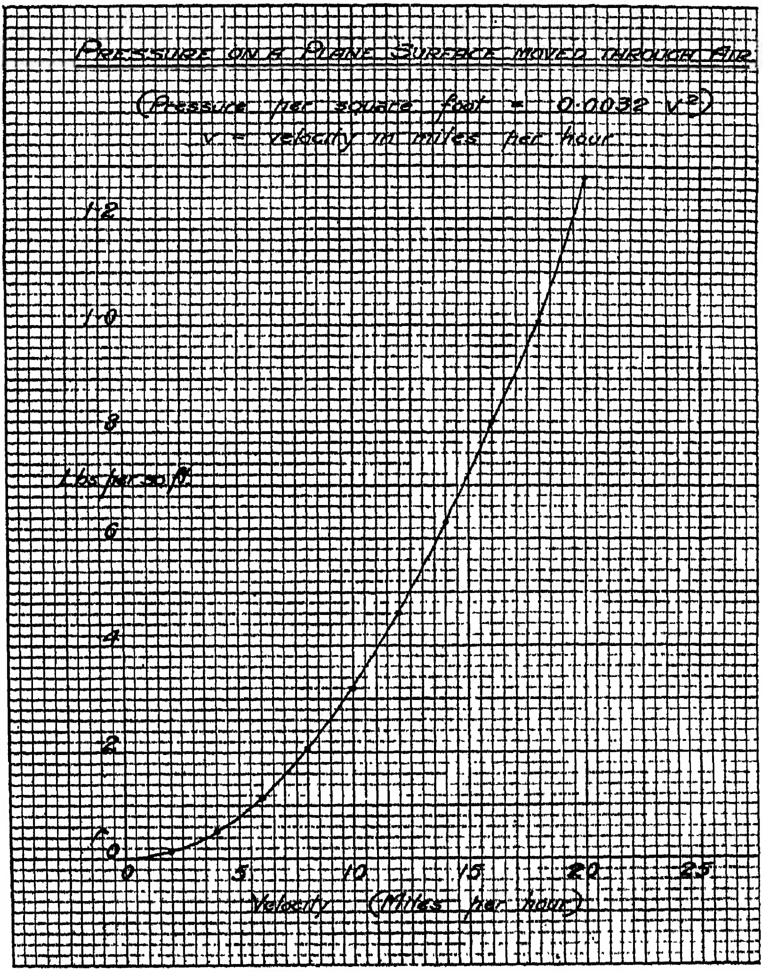


FIG. 1.—Wind Resistance Curve.

The converse course to the above is then followed, the total resisting force per ton being first calculated, and the components separated out.

To assist in calculations a table of data regarding road

resistance (Table I) and a graph showing the force exerted on a plane surface due to wind pressure are given (Fig. 1).

Authorities for Figures in Table I.—(*a*) and (*c*) W. D. Sheers, *Metropolitan-Vickers Gazette,* March 1921. (*b*) C. G. Conradi. (*d*) W. Worby Beaumont.

CHAPTER II

BATTERIES FOR ROAD VEHICLES

Batteries for Road Vehicles.—The provision of storage capacity for the energy required for propelling electric road vehicles has always been the chief difficulty in the way of their development. The basic theory of accumulators has not progressed materially since they were first invented, so that it is only necessary to recapitulate the well-known principles of action of secondary cells to give the reader all that is required for electric vehicle maintenance purposes. The quantitative treatment of the energy content per unit of weight also shows the best possible results which can be got from cells working on the standard principles, and how far the available examples are from the ideal cells. The main results of about three decades of development have been in the direction of improved mechanical strength, and this feature is illustrated by descriptions of examples of present-day traction accumulator practice.

Two types of accumulators are in general use, namely, those of the lead-sulphuric acid type, and those of the iron-nickel-potassium hydrate type. These types will hereafter be designated by the commonly used terms Lead Accumulator and Alkaline Accumulator respectively.

In both types the general principle lies in storing up energy in chemical form and liberating it as electrical energy.

The first type to be dealt with is the Lead Accumulator. This type gets precedence because it is much older and is more widely used than the Alkaline type.

The Lead Accumulator.—The lead accumulator consists

essentially of two sets of plates in a solution of sulphuric acid, the whole being contained in a suitable box or holder when in a charged condition. The active material of the positive plates consists of lead peroxide, and the negatives of spongy lead. The plates can be recognised by their colours, the positives being chocolate brown, while the negatives are slate grey. In practice there are usually several positive and negative plates in a single cell, the positives and negatives being arranged alternately with some class of insulating material separating them.

Chemical Phenomena during Discharge and Charge of a Lead Accumulator.—Suppose a lead accumulator cell to be in a charged condition, and let the positive and negative plates be joined by an electrical conductor. An electric current will then flow from the positive through the conductor to the negative, and will then return through the electrolyte (sulphuric acid) to the positive. This is the operation of discharging the cell. During the discharge, chemical changes take place. Hydrogen is liberated at the positive electrode and SO_4 at the negative. The hydrogen reduces the lead peroxide and forms water at the positive electrode, and lead sulphate is formed at the negative.

The discharge, therefore, may be represented by the chemical equations :—

$$\left.\begin{array}{l} PbO_2 + 2H = PbO + H_2O \\ PbO + H_2SO_4 = PbSO_4 + H_2O \end{array}\right\} \text{at the positive plate, and}$$

$$Pb + SO_4 = PbSO_4 \quad \text{at the negative plate.}$$

The chemical reaction lasts until the lead peroxide on the positive plate and the spongy lead on the negative are transformed to lead sulphate. The density of the sulphuric acid solution decreases during the discharge due to the passage of SO_4 into the plates and the formation of the water.

The passage of an electric current through the cell in the reverse direction brings about a converse chemical reaction,

which may be expressed by the equations $PbSO_4 + SO_4 + 2H_2O = PbO_2 + 2H_2SO_4$ for the positive plates and $PbSO_4 + 2H = Pb + H_2SO_4$ for the negative plate.

At the end of the charge the plates and electrolyte are in their original condition, and the cell is once again ready to send electric currents through an external circuit.

The whole of the charges which take place may be represented by the chemical formula :—

$$\overbrace{\underset{PbO_2}{+} \quad \underset{+\ Pb}{-} \quad \underset{+\ 2H_2SO_4}{\text{electrolyte}}}^{\text{Charge}} \qquad \overbrace{\underset{2PbSO_4}{+ \text{ and } -} \quad \underset{+\ 2H_2O}{\text{electrolyte}}}^{\text{Discharge}}$$

If charging is continued after the completion of the chemical reactions at the plates, the only effect of the current is to liberate hydrogen and oxygen from the water.

The above equations give a means of determining the weights of active material required for an accumulator of given storage capacity.

A current of 1 ampere flowing for one hour will liberate 3·86 grams of metallic lead from a lead salt; conversely, 3·86 grams of spongy lead will be required at the negative plate in order to give an output of 1 ampere-hour.

The weight of lead peroxide required at the positive for 1 ampere-hour will be $\frac{206{\cdot}5 + 32}{206{\cdot}5} \times 3{\cdot}86 = 4{\cdot}46$ grams, 206·5 being the atomic weight of lead and 16 that of oxygen. The minimum weight of electrolyte is determined from the fact that two molecules of sulphuric acid are required at each plate if two atoms of hydrogen are liberated. The molecular weight of sulphuric acid is 98, so that 98 grams of sulphuric acid correspond to 1 gram of hydrogen. Now 1 ampere-hour liberates 0·0373 gram of hydrogen, so that the weight of sulphuric acid required per ampere-hour is $0{\cdot}0373 \times 98 = {\cdot}366$ grams.

The total weights of active materials per ampere-hour are therefore as follows :—

Spongy lead	3·86 grams.
Lead peroxide	4·46 ,,
Sulphuric acid	3·66 ,,
Total	11·98 ,,

It should therefore be possible to get an output of 38 ampere-hours, or since the voltage is approximately 2 volts, 76 watt-hours per pound of active material of the complete cell. In addition to the active material, a cell must, of course, have a box or container, plate frames for holding the lead peroxide and spongy lead and insulating separators between the plates. It is also impracticable to work with concentrated sulphuric acid, so that a cell must contain a considerable amount of water as a solvent for the sulphuric acid. The result of these requirements is that no commercial lead cell has yet been made which gives more than 5 to 6 ampere-hours, or 10 to 12 watt-hours per pound of complete cell. This shows that the ratio of the actual output per unit of weight to the best possible output per unit of weight is $\frac{(10 \text{ to } 12)}{76} \times 100$ or, say, 16%. This point will be considered more closely in the section dealing with the construction of cells.

The electrical characteristics of lead cells will now be dealt with in greater detail. The first aspect to be considered is the voltage of a cell.

When considering the question of weights, the voltage of a cell was stated to be about 2 volts. In reality the voltage of a lead cell varies between the practical limits of about 1·7 to 2·5 volts. The factors which affect the terminal voltage are the state of charge, the magnitude and direction of the current passing through the cell, the internal resistance and the temperature.

Let the total E.M.F. of the cell be denoted by Ei
,, the terminal voltage of the cell be denoted by Et
,, the current passing through the cell be denoted by I
,, the resistance of the cell be denoted by R

then $$Et = Ei \pm IR,$$

the + sign being used when the cell is being charged, and the − sign when it is being discharged. The relation is

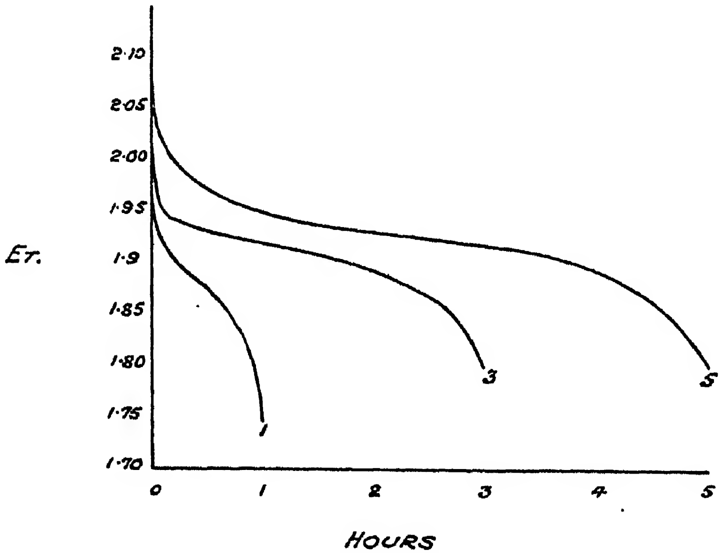


FIG. 2.—Terminal Voltages of Lead Cells for various Discharge Rates.

complicated by the fact that neither Ei nor R is a constant quantity. The voltage of a typical lead cell for use on a battery vehicle is shown in Fig. 2, which gives the terminal voltage as a function of the time for discharge currents varying from normal to five times normal rate. It will be noted that the discharge is stopped in all cases when the terminal voltage has reached 1·7 volts. The lower limit has been established by experience, as it is found that discharging below 1·7 volts causes very rapid deterioration of lead cells. Fig. 3 gives similar curves for different rates of charge of the same cell.

The E.M.F. and resistance of a cell are also dependent on the specific gravity of the electrolyte.

Capacity of Lead Cells.—The capacity of a cell is generally measured in ampere-hours. It is determined by the number of ampere-hours delivered by the cell between definite limits of voltage or specific gravity.

The capacity of a cell is not a fixed quantity, but varies with the conditions under which it works, especially with the rate of discharge, the capacity falling off rapidly with the rate

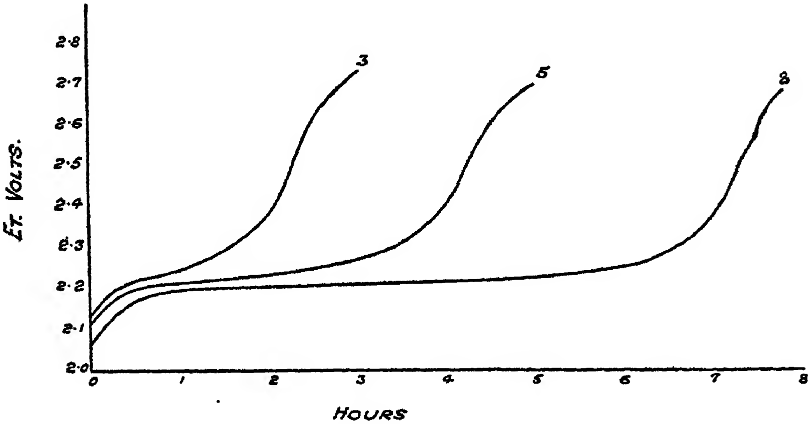


Fig. 3.—Voltages of Lead Cell during charge for different Rates of Charge.

of discharge. The capacity of a cell for varying rates of discharge is given in Table II.

Table II.

Variation of Capacity of Lead Cells with Discharge Rate.

Discharge Current.	Capacity (Actual).	Ampere-hours (Percentage).
1. Normal 100% 5 hours' rate . .	83	100%
2. Twice ,, 2½ ,, . .	69	83%
3. Three times 100% 1·66 hours' rate .	58	70%
4. Four ,, 1·25 ,, .	55	66%
5. Five ,, 1 ,, .	50	60%

The relation between the capacity and rate of discharge has been stated mathematically by Peukert in the following way :—

If C = Capacity of cell in amp.-hours when the discharge time is T

and Co = Capacity of cell in amp.-hours when the discharge time is To

then $C = Co \left(\frac{T}{To}\right)a$ and $a = 0{\cdot}3$.

The constants must be investigated empirically for each particular type of cell considered.

The capacity of a cell is also dependent on the following additional factors :—

1. The thickness of the plates.
2. The porosity of the active material.
3. The specific gravity of the electrolyte.
4. The purity of the materials in the cells.
5. The temperature of the cell.

Regarding the influence of plate thickness, it can only be stated that for equal weights of active material thin plate accumulators show higher capacities than thick plate ones, if the cells are discharged in the same time. They would, of course, show same capacities if discharged to the same extent. The advantage of the thin plate lies wholly in the greater ease with which the electrolyte reaches the active materials.

The advantage of high porosity in giving greater discharges in a given time is also due to the above reason.

Research has shown that the capacity of cell reaches a maximum, and its internal resistance a minimum when the specific gravity of the electrolyte is about 1·25. It is, however, necessary to use sulphuric acid of a lower density, say 1·24, in order to prevent too rapid sulphation of the plates by direct action of the sulphuric acid when the cells are not working.

The influence of impurities on the capacity of cells is so

important that every care must be taken to ensure that the purest possible materials shall be used. Various researches on this subject have been conducted, but no general rule other than the fact that all impurities diminish the capacity of a lead cell has been established.

The capacity of a lead cell increases with rise of temperature, but this is not of practical benefit, as the life of a cell decreases rapidly with rise of temperature, so that it is essential to operate cells at low temperatures for economic reasons.

Ampere-hour and Watt-hour Efficiencies.—The ampere-hour discharge obtained from an accumulator is always less than the charge, since some of the quantity of electricity which passes through the cell is spent in splitting up the water in the electrolyte. The ampere-hour efficiency is, however, high, being about 90% under commercial conditions, while laboratory tests can give up to about 96%. The watt-hour efficiency is much lower, due to the resistance losses in the cell during charge and discharge. In ordinary working, the watt-hour efficiency of a cell may be taken as about 75%, but to attain even this figure the charging must be carried out very carefully.

If a cell is left on open circuit, a slow self-discharge occurs which has an important effect on the efficiencies obtained in ordinary practice.

It is, of course, self-evident from what has been said regarding the influence of rate of discharge on capacity that the efficiency of a cell will depend to a great extent on the rates of charge and discharge, and the figures given above are for normal rates.

The above figures are given on the understanding that the discharge follows immediately after the charge.

The Life of a Lead Accumulator.—During each charge and discharge of a cell a certain amount of the active material is shed from the plates, and is deposited in the bottom of the container. This is the principal factor in determining the

length of useful life of a cell which is in regular use. It is possible to determine the life of a cell in cycles of charge and discharge. Vehicle batteries are usually guaranteed for two years, the guarantee stating that the capacity at normal rate of discharge will not fall below 80% of its guaranteed value in that period of time. This means that battery-makers expect their products to have a useful life of 600 to 700 cycles of charge and discharge.

The life of a lead battery is, however, very considerably shortened if it is discharged at high rates, subjected to high temperatures, or left uncharged for long periods.

The ratings given by battery-makers have been arrived at after long experience, and users will always get the best results when they operate their batteries as nearly as possible at normal rates and use them as regularly as possible.

Construction of Lead Accumulators for use in Electric Vehicles.

The constructional elements of a cell are the positive and negative plates, separators, containers and terminals.

No attempt will be made to trace the development of plate construction, but typical cells which have proved successful in practice will be described, and it is hoped that the descriptions given will give the reader a fair idea of modern practice.

The first type chosen for description is the **Exide Ironclad Cell,** made in England by the Chloride Electric Storage Co., Ltd., of Clifton, Manchester. This cell is of very special construction and has given excellent service over a considerable period of years. The various components of this and of the other cells described will be dealt with in the order given above.

Positive Plate.—The positive plate shows the most radical departure from ordinary practice. The main frame consists of a number of plates of antimonial lead rods held together at

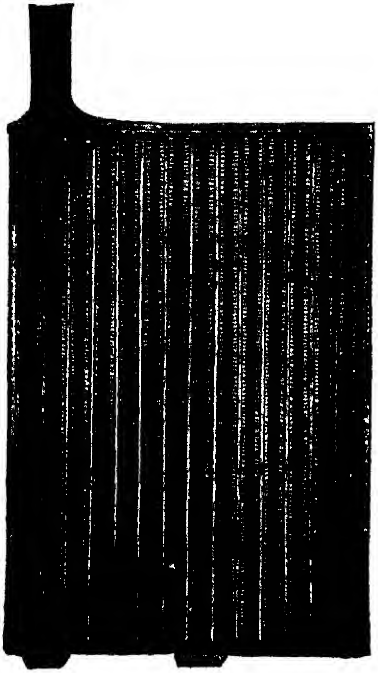


FIG. 4.—Exide-ironclad Positive Plate.

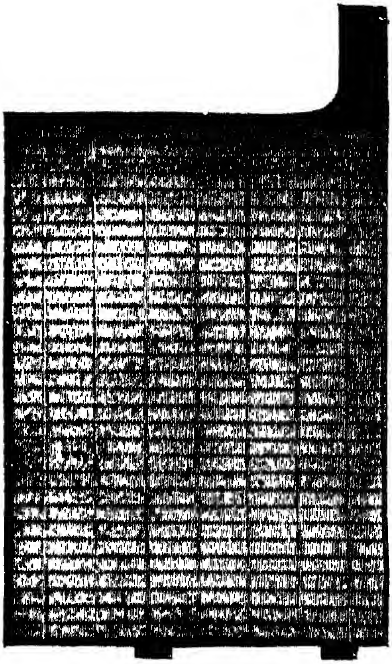


FIG. 5.—Exide-ironclad Negative Plate.

FIG. 6.—Exide-ironclad Separator.

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their ends by lead castings. The rods form cores to slotted cylindrical ebonite sheaths. The spaces between the rods and the ebonite sheaths are filled with the active material. The function of the ebonite sheath is to retain the active material in position, and the slots serve as inlets for the electrolyte. Fig. 4 shows a positive plate with 15 vertical cylindrical elements. The construction of such a plate is a remarkably fine piece of work, and great credit must be given to the engineers who have had the ingenuity and patience to develop it, in face of the difficulties caused by the poor mechanical strength of the materials used.

Negative Plate.—The negative plate of the Exide Ironclad Cell (Fig. 5) consists of a grid of hard antimonial lead. The grid sections support and contain the active material. The superior mechanical strength of the negative plate makes it unnecessary to have any special retaining covers such as are necessary with the positive plate.

Separators.—The separators between the positive and negative plates consist of very thin sheets of specially prepared wood. A typical separator is shown in Fig. 6.

Assembly of Plates.—An extension (or "lug") is provided on each plate, and the plates are assembled so that the positive lugs are along one side of the cell and the negatives along the other. Connecting strips join corresponding lugs, and each of the strips has a terminal post or pillar. The construction of the terminal posts is of very considerable importance, and the arrangements made by the Chloride Co. are very sound and convenient. Inter-cell connections have to be made by burning, but this work is very easily done by means of a low voltage electric arc supplied from three or four traction cells. A special tool is provided for disconnecting cells.

Containers.—The containers consist of ebonite boxes, on the bottoms of which are bridge pieces which carry the weight of the elements and are arranged to allow space for the deposit of sediment from the plates. The lids of the containers are

also of ebonite, and special arrangements are made for sealing and venting the cells. A complete battery is shown in Fig. 7.

Kathanode Electric Vehicle Batteries.—These batteries are made by the D.P. Battery Co., Bakewell, Derbyshire.

Positive Plate.—The chief feature of this battery lies in the protection of the positive plate. The ordinary positive plate as used in stationary batteries is readily disintegrated and would give poor service on a road vehicle. The D.P. positive plate frame consists of a series of rectangular grids which serve as retainers for the active material (Fig. 8). The whole plate is then wrapped in glass wool, which prevents the active material from falling away from the plate and yet allows the electrolyte to get free access.

The *Negative Plate* is very similar to the positive, but, of course, no glass-wool wrapping is provided.

Separators.—In addition to the glass wool there is a thin wood separator between each pair of plates.

Containers.—These are of the ebonite type, and the tops are of very simple construction with india-rubber stoppers. The assembly of a D.P. Cell is shown in Fig. 9.

The Philadelphia Diamond Grid Battery.—The *Positive Plate* of the Philadelphia Diamond Grid Battery is provided with grids which have diagonally arranged members (Fig. 10). It is claimed that this arrangement is very much superior to a construction having horizontal and vertical grid members, and the claim appears to be well justified in practice.

The positive plate is surrounded by a hard rubber retainer which is perforated with rectangular slots. Rectangular slots are preferable to circular ones, because of the fact that for a given area of slot they allow the passage of a smaller particle of active material.

The *Negative Plate* is of the usual flat type.

Separators.—Wood separators are used, and the Philadelphia

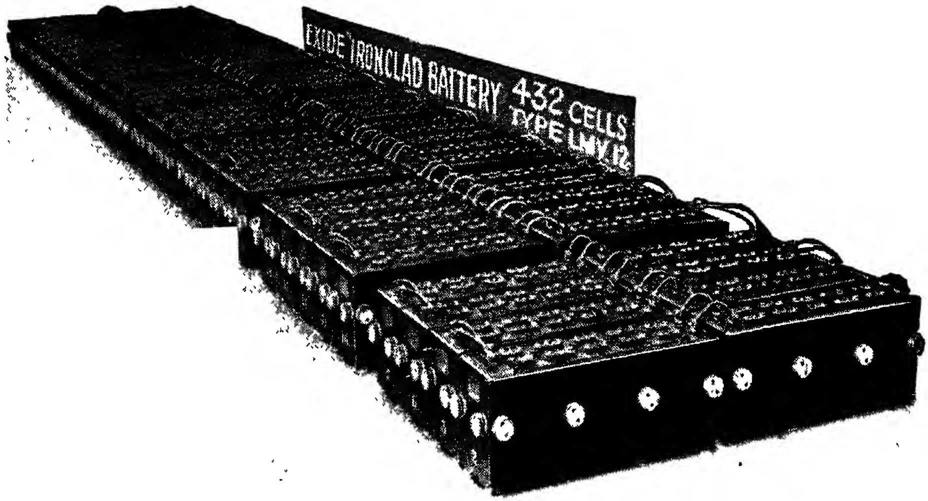

FIG. 7.—Complete Exide-ironclad Battery.

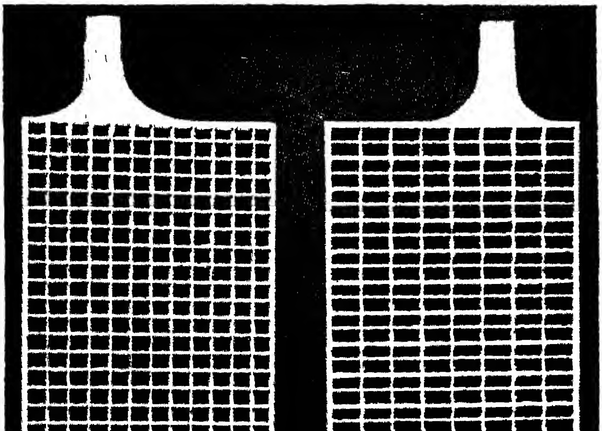

FIG. 8.—Positive and Negative Plate Frames of D.P. Cell.

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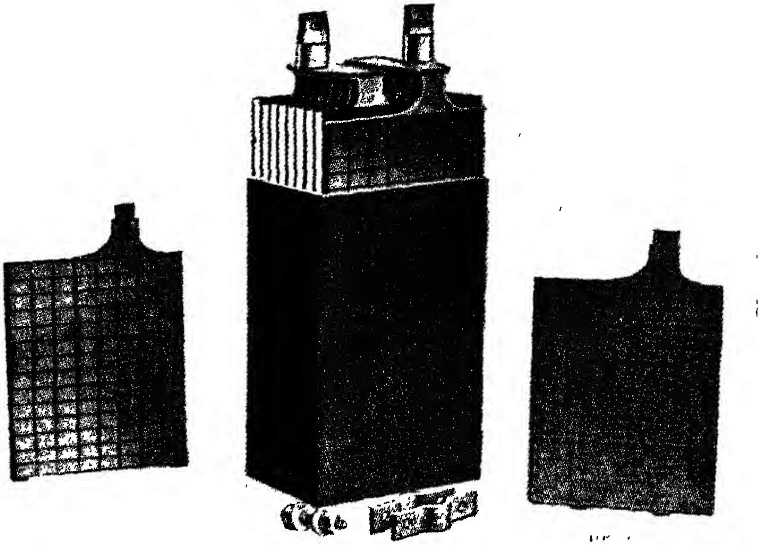

FIG. 9.—Assembly of D.P. Cell.

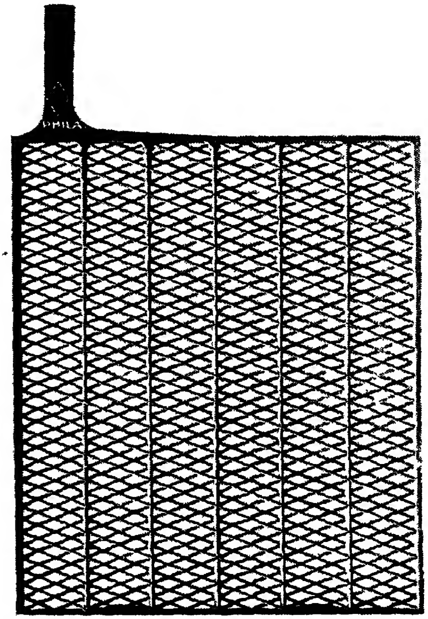

FIG. 10.—Philadelphia Diamond Grid Frame.

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Company claim to have made a definite advance in the choice of material and method of working of these.

Containers.—These are of moulded ebonite and of distinctive design. The tops are slightly raised above the sides, so that it is very easy to keep them clean, and the filler caps are very conveniently arranged.

Connections.—The positive posts are provided with a permanently connected strip for making the connections with the adjacent cells. The negative connections are screwed. This scheme eliminates the trouble of corrosion at the positive post, which causes trouble with many connectors, and yet allows for very simple disconnection. Fig. 11 shows an assembled cell with container broken away.

The author feels compelled to pay a tribute to the publicity staff of the Philadelphia Company in producing their booklet, " The Inside Story of the Philadelphia Diamond Grid Battery." This shows the construction of a cell in the most vivid way possible, and enables anyone to get a grip of the matter in a very few minutes. The literature of other battery-makers mentioned in the present volume is also excellent and thorough, but none of it seizes the imagination in the way the above-mentioned booklet does.

The Ky Battery of the A.F.A. Company.—This battery is made by the Accumulatoren-Fabrik Aktiengesellschaft, Berlin.

Positive Plates (Fig. 12).—These are of the ordinary flat plate type, but it is claimed by the makers that their durability is greater than that of plates made by other manufacturers.

Negative Plates (Fig. 12).—The negative plates are of the usual pasted type; the makers, however, claim that the tendency to shrink and crack is greatly minimised by their special process of pasting.

Separators.—The A.F.A. separators consist of a sheet of perforated ebonite placed against the positive plate and a thin wood sheet against the negative.

Containers.—The containers are vulcanised rubber boxes with prism supports at the bottom in the usual way. The lids are loose and are not sealed, but the box sides project above the lids so that no spilling can occur. This renders it very easy to take out the plates and separators for inspection or repair. Fig. 13 shows the construction of a complete cell.

Connectors.—These are screwed on both positive and negative terminals. This has proved to be the weakest feature of the A.F.A. battery, but if the terminals are disconnected and cleaned, say, every two months, corrosion troubles are eliminated.

Alkaline Batteries.

The obvious fragility of the lead battery has led many investigators to go into the question of producing an accumulator of a more durable type. An enormous amount of work has been done, but the only direction in which any commercial success has been attained has been in the development of accumulators which use alkaline electrolytes. As long ago as 1885 an accumulator was patented in which the active material of the positive plate consisted of oxide of copper, silver manganese or nickel, the negative of copper, silver, iron, etc., and the electrolyte of sodium or potassium hydrate. Later an accumulator was constructed by Waddel and Entz, using copper and zinc plates in potassium hydrate.

The first real step towards the perfection of the modern alkaline battery seems to have been Jungner's enunciation of the fundamental principle of these cells, namely, the fact that the electrolyte is unaltered during the charge and discharge, and that all chemical changes take place in the electrodes.

Several types of accumulators were tried, using different kinds of electrodes in sodium or potassium hydrate, but none attained commercial success until Edison discovered the type which was patented in 1901. This accumulator used nickel hydrate and iron oxide electrodes, and was the direct pre-

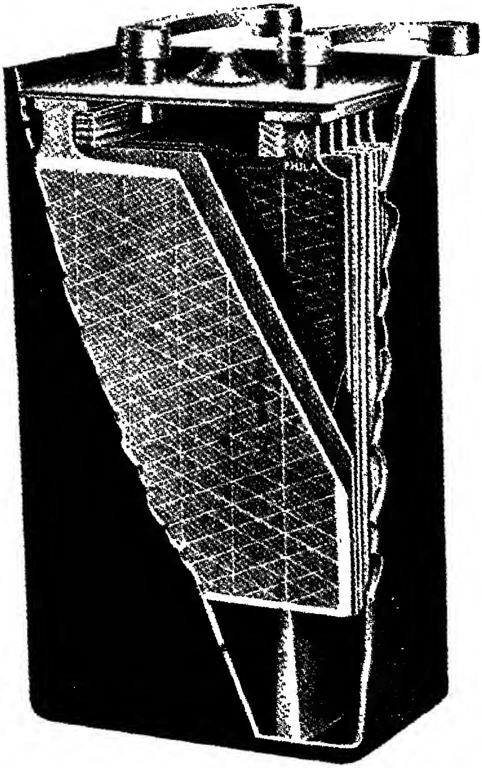

FIG. 11.—Philadelphia Thin Plate Cell.

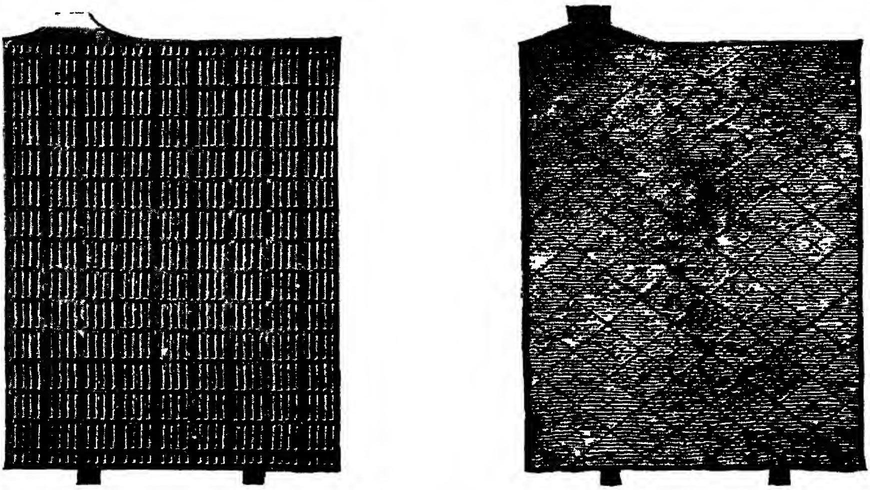

FIG. 12.—Positive and Negative Plates for A.F.A. Cell.

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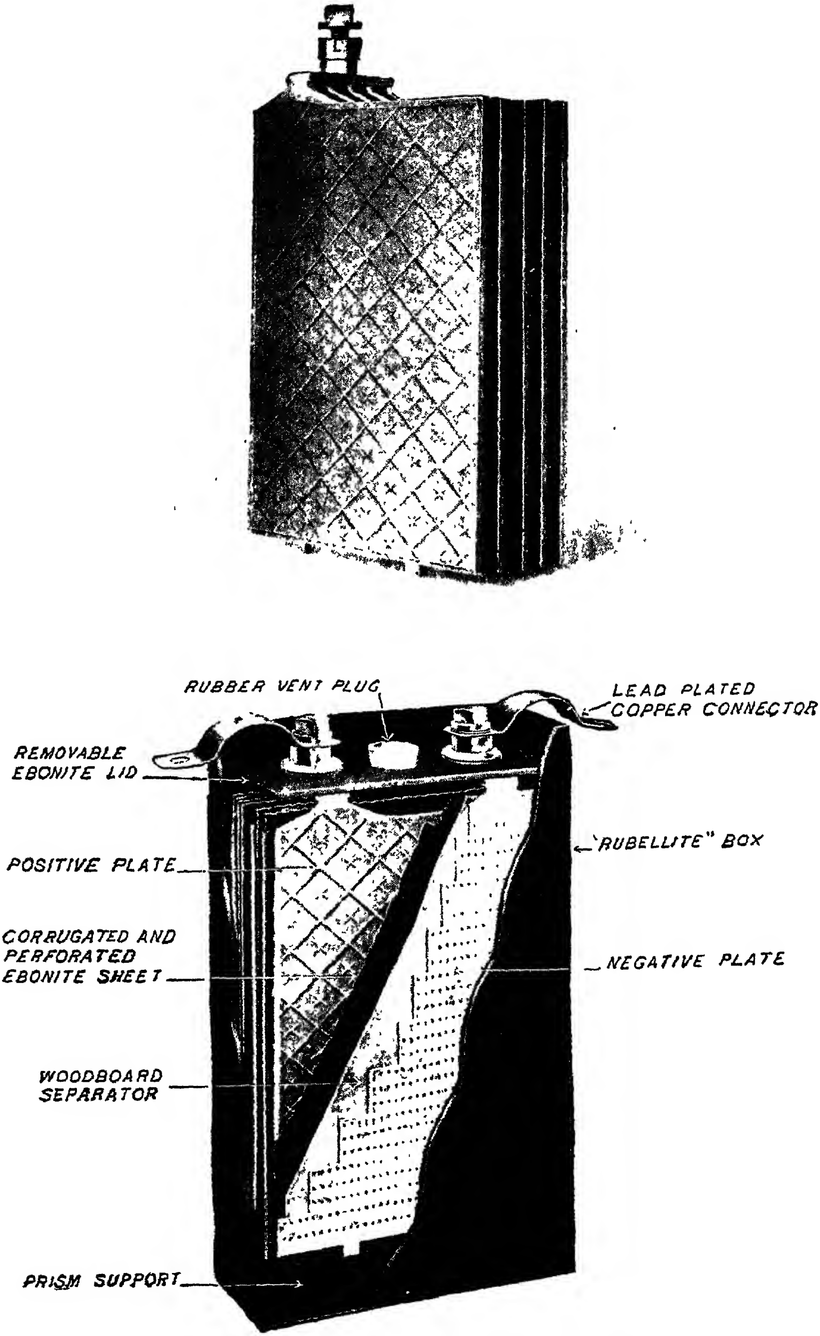

FIG. 13.—Construction of A.F.A. Cell.

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decessor of the present-day type, which was introduced about 1910. This accumulator will now be described in some detail.

The Edison Accumulator.

CHEMICAL REACTIONS—ACTIVE MATERIALS—MECHANICAL CONSTRUCTIONS — VOLTAGE CHARACTERISTICS — CAPACITY — AMPERE-HOUR AND WATT-HOUR EFFICIENCY—LIFE.

Chemical Reactions in Edison Accumulators.—There is as yet no generally accepted series of reactions which correspond exactly to the different states of the alkaline accumulator. The explanation of the changes which take place in an Edison cell as given by the manufacturers is as follows. In a new cell, the positive plate active material is nickel hydrate, and that of the negative is iron oxide, the plates being immersed in a strong solution of potassium hydrate. The first charge causes the nickel hydrate to become more highly oxidised, the change being signalised by the colour altering from dark green to black. The negative active material is at the same time reduced, and becomes chemically pure iron. Subsidiary reactions may take place in the electrolyte, but as it does not alter in composition during the charge it may be considered to function solely as a conductor between the plates. On discharging a cell, the nickel oxide becomes reduced to a certain extent, but never reaches its original condition. The essential feature of the cell is the electrolytic carriage of oxygen from negative to positive plates during charge, and from positive to negative during discharge. The Edison cell is rather sensitive to temperature variations, and becomes very inactive at low temperatures.

The minimum weight of active material in a cell is approximately 4 kilograms per kw.h., but in practice 8 kilograms are required.

Mechanical Construction of the Edison Cell.—*The Positive Plate.*—An Edison positive plate consists of a number

of helical tubes, made from finely perforated nickel steel strip, which serve as containers for the active material. The tube filling consists of alternate layers of nickel hydrate, and flakes of metallic nickel. The filling is closely compressed, over 300 layers being put into each tube. The tubes are 4 inches long and $\frac{1}{4}$ inch in diameter. The purpose of the metallic nickel is to give increased conductivity, the nickel hydrate alone being a comparatively poor conductor of electricity. The tubes are reinforced by steel rings. A complete positive plate consists of a number of unit tubes mounted in a light nickelled steel frame. A tube and a complete positive plate consisting of 30 tubes are shown in Fig. 14.

The Negative Plate.—The negative plate also consists of a series of suitably mounted units. In this case the units are flat, oblong pockets instead of cylinders. The filling consists of iron oxide and mercury, the mercury being used to improve the electrical conductivity. The pockets and frame are again made of nickelled steel. Good contact between the active material and the containing pockets is obtained by subjecting the units to heavy pressure. This treatment also helps to prevent the active material from becoming loose. A negative pocket and plate are shown in Fig. 15.

Separators.—Thin rubber strips separate the positive and negative plates. Rubber is also used for insulating the plates from the container.

Container.—The container consists of a corrugated sheet steel box with a welded-on lid on which is mounted a filling and gas-escape valve. The assembly of plates is shown in Fig. 16. The mechanical construction of the Edison cell is extremely sound, great rigidity and strength being obtained with the minimum of inactive material.

Inter-cell Connectors.—The terminals of each cell are machined to a conical shape to which a steel connector bored and reamered to suit the cone is fitted. A copper rod of the required length is sweated into the connector.

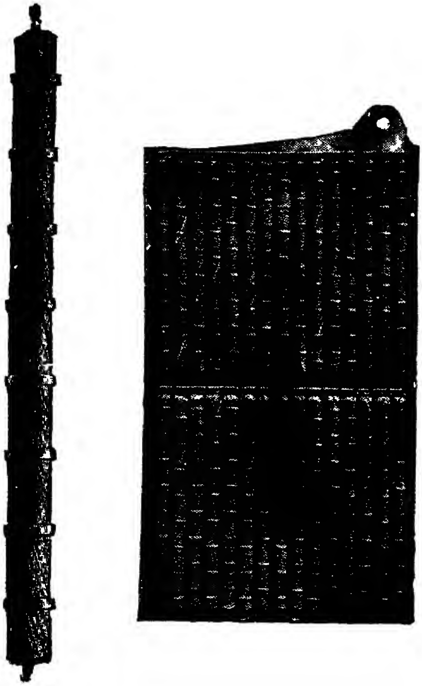

FIG. 14.—Complete Positive Plate and Tube for Edison Cell.

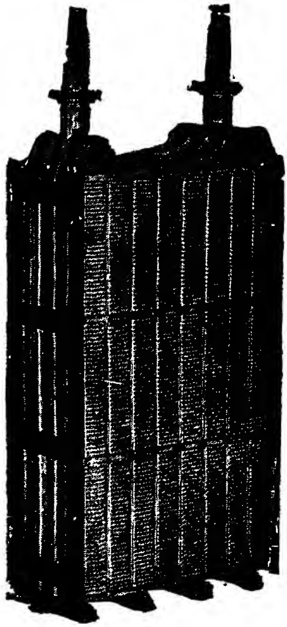

FIG. 16.—Assembly of Plates for Edison Cell.

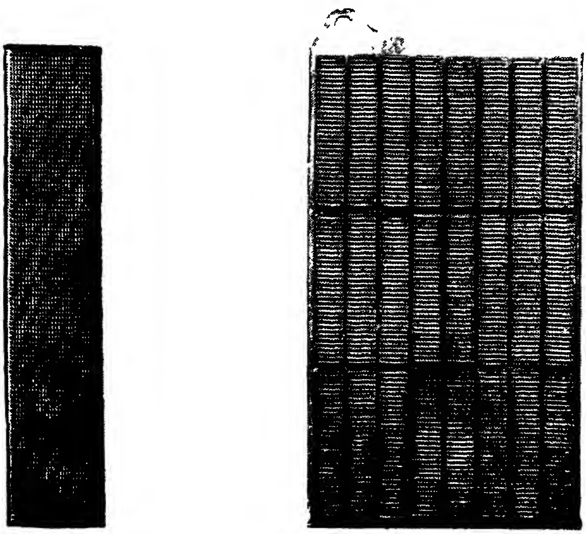

FIG. 15.—Complete Negative Plate and Pocket for Edison Cell.

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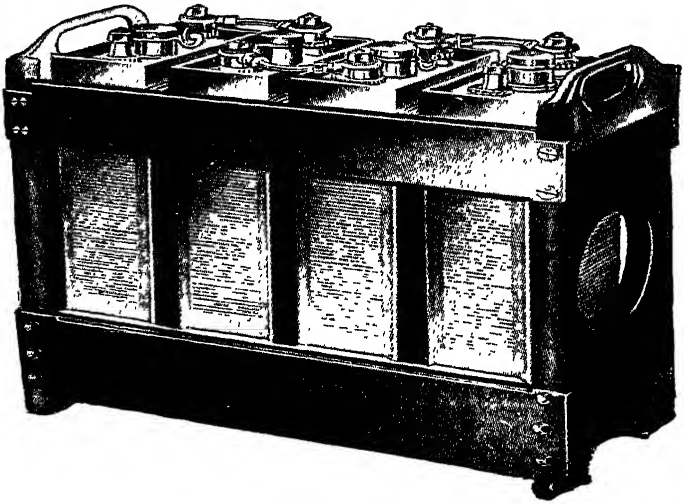

FIG. 17.—Edison Battery Unit.

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Battery Units.—Groups of cells are usually mounted in hard-wood crates for convenience in handling. (See Fig. 17.)

Electrical Characteristics of Edison Cell.—*Voltage.*—During a charge the voltage of a cell rises from about 1·55 to 1·82 volts, while during a discharge it falls from 1·84 to 1·00. The average voltage at the normal rate of discharge is 1·2 volts per cell. The average charging voltage at normal rate is 1·67 volts.

Capacity.—The ampere-hour capacity of an Edison cell does not vary much with the discharge rate. It varies according to the size of the unit cell from 7·5 to 12 ampere-hours per pound of complete assembled battery. The watt-hour capacity of a 40 ampere-hour cell is 11 watt-hours per pound, while a 300 ampere-hour cell gives about 15 watt-hours per pound. The watt-hour capacity is, of course, much more dependent on the rate of discharge than is the ampere-hour capacity, due to the internal resistance of the cell.

Efficiency of Edison Cells.—The ampere-hour efficiency of a cell is from 75 to 80% at normal rates of charge and discharge. The corresponding watt-hour efficiency is from 55 to 60%. With partial charges (boosts) and discharges the ampere-hour and watt-hour efficiency may be as high as 95% and 68% respectively. It is extremely important to note that low rates of charge are highly inefficient.

The Ni-Fe Accumulator.—This accumulator has been evolved directly from the pioneer alkaline cell of Dr. Valdemar Jungner. The cell has been on the market since 1911, and is the principal rival of the Edison cell.

Positive Plate (Fig. 18).—The Ni-Fe positive plate is made up of oblong pockets containing the active materials. The main ingredient of the pockets is nickel hydrate. Other materials not disclosed by the manufacturers are added to increase the electrical conductivity. The unit pockets are assembled in a steel frame, and are pressed hydraulically just as in the case of the Edison cell.

Negative Plate.—The negative plate is exactly similar in construction to the positive plate, the filling of the pockets in this case being iron oxide, and chemicals to prevent self-discharge.

Separators.—These consist of Para rubber strips.

Container.—A plain steel container with welded joints is used. The terminals and filler do not exhibit any special features.

Electrolyte.—This is a solution of potassium hydrate in distilled water.

Electrical Characteristics.—These are generally similar to those of the Edison cell, but the smaller plate spacing gives a lower terminal resistance, and therefore a higher watt-hour efficiency. The Ni-Fe accumulator gives an ampere-hour efficiency of 75 to 80%, and a watt-hour efficiency of 60 to 65%. The activity of the Ni-Fe cell is not seriously affected by the temperature over quite a wide range. Fig. 19 shows the assembly of plates and a complete cell.

Comparison between Alkaline and Lead Batteries.—The question as to which is the better of the above types of battery for electric vehicle work is one which is continually being asked. It is, however, impossible to give a definite answer to the query. If a referendum of all concerned with electric vehicle work were taken, it is probable that the workmen engaged in the actual work of maintaining batteries would be overwhelmingly in favour of the Alkaline type, while those who had given close attention to the economics of the subject would favour the lead battery, the broad reasons for these judgments being that the Alkaline battery is much the more robust and easily maintained, while the Lead battery is cheaper and more efficient. The differences which can be fairly accurately established are given on page 27.

The lead battery has a great advantage in its much lower internal resistance, which is only partially allowed for by the higher watt-hour efficiency given above. A further minor

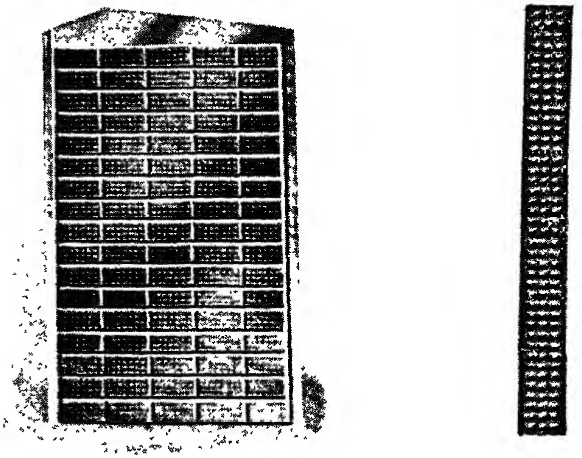

FIG. 18.—Ni-Fe Positive Plate and Pocket.

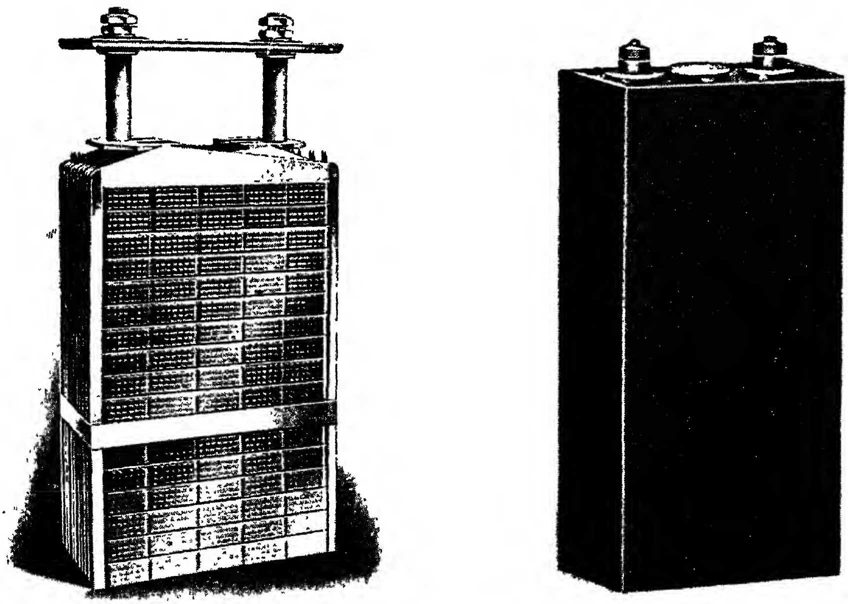

FIG. 19.—Plate Assembly for Ni-Fe Cell.

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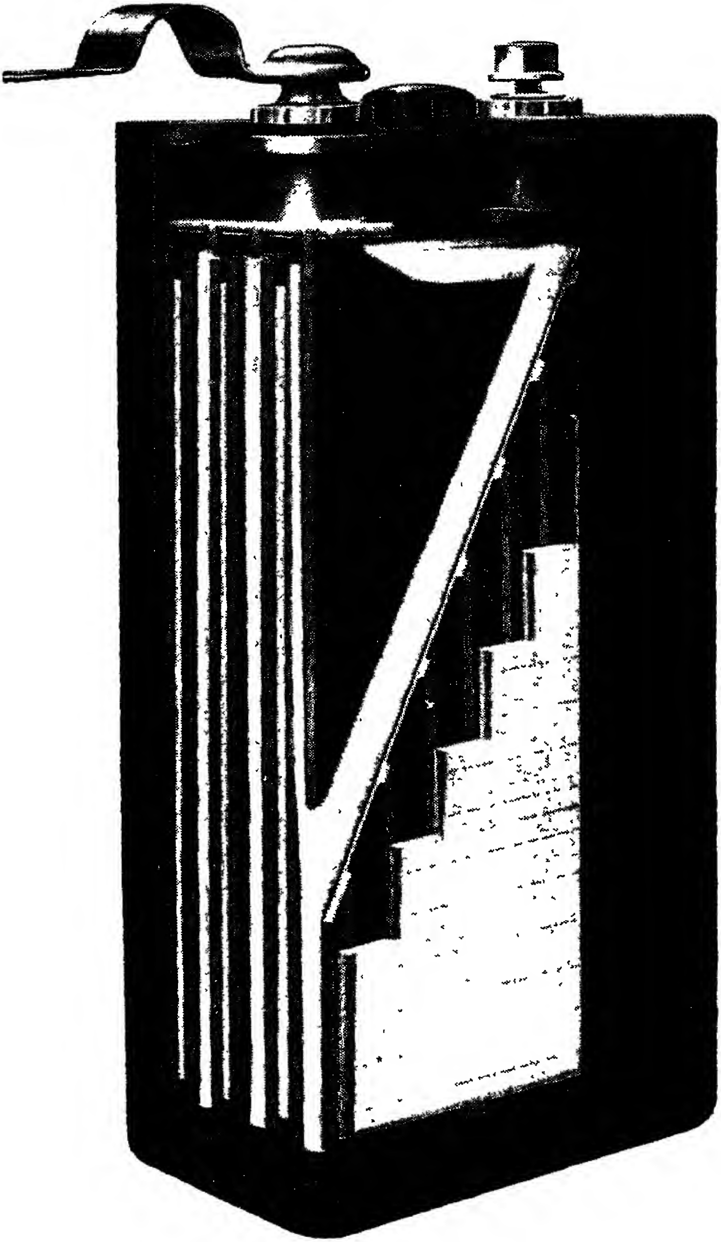

FIG. 19*a*.—Construction of Tudor Battery.

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advantage for the lead battery is that it is not effected by low temperatures to the same extent as its rival.

	Alkaline.	Lead.
Watt-hour efficiency	59%	75%
Watt-hours per inch^3	0·74	0·60
,, ,, pound	15	9–12
Initial cost £/kw.h.	30	8·4
Life	6–8 years	2–3 years

A point against the alkaline battery which is not generally realised is that charging must be done at high rates, low rate charging being practically useless. These are the principal points of comparison between the two classes of batteries. In the opinion of the present writer, the evidence is largely in favour of the lead type at the moment, but if anything could be done to bring down the first cost and improve the chemical activity of the alkaline battery the tables would immediately be turned. There are very distinct possibilities that the latter requirements will soon be reached, and the consequent increased demand should have the result of reducing the price of the cells.

Recent Developments in Battery Construction.—Battery makers are at present showing that they do not intend to allow matters to stagnate so far as the design and construction of vehicle batteries are concerned. Although they have not yet hit on any revolutionary principle, they have carefully analysed the whole situation and are putting forward propositions which should materially improve the economic position regarding the supply of batteries. Most of the development work has been done on lead batteries, but there has been one important addition to the ranks of alkaline type.

New lead batteries have been introduced by the Tudor Accumulator Company, Limited, and the Ace Battery Company, Limited. The new alkaline battery is of French manufacture, and is handled in Britain by the Iron and Nickel Battery Company, Limited.

The Tudor Accumulator Company has been associated with the electric vehicle movement since its commencement. Until recently the standard Tudor vehicle battery was of the thin flat plate type, and was generally on the same lines as the A.F.A. battery, which has already been fully described. The latest design shows extensive modifications (Fig. 19*a*). The positive plate is now surrounded by an envelope of glass wool, similar to that used by the D.P. Battery Co. Thick, deeply grooved wooden separators serve to reduce the danger of short circuiting between the plates, and at the same time give very definite circulating paths for the electrolyte. Sealed vulcanite containers are used. The connections may be of the burned or bolted type as desired. The output aimed at is 10 watt-hours per pound, and it is expected that a very long life will be obtained.

The Ace Battery is designed to give an output of 12 watt-hours per pound, and is guaranteed for a period of two years. The general construction is quite normal, but the type of separator used is novel (Figs. 19*b* and *c*). It consists of narrow interwoven strips of wood forming a sort of lattice construction. The value of this innovation lies in the fact that it is comparatively easy to get flawless strips of wood of the width required for the lattice separator. It is much more difficult to get absolutely sound pieces of the size required for the conventional type of separator.

The Ionic Battery (Figs. 19*d* and *e*) is of the nickel-iron type, and in principle does not differ from the Edison and Ni–Fe batteries. Its mechanical construction resembles that of the Ni–Fe battery, both + ve and — ve electrodes being of the flat plate type. The plate construction and arrangement adopted reduce the internal resistance of the Ionic cell below that of an Edison cell of the same capacity. The internal resistance R of an Ionic cell of C ampere-hour capacity is given by the empirical formula $R = 0{\cdot}43/C$, *e.g.*, a 300 ampere-hour cell would have an internal resistance of $0{\cdot}43/300 = 0{\cdot}0014$

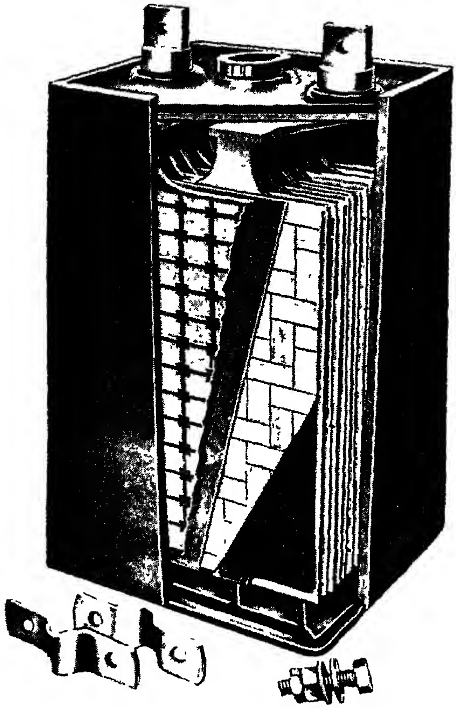
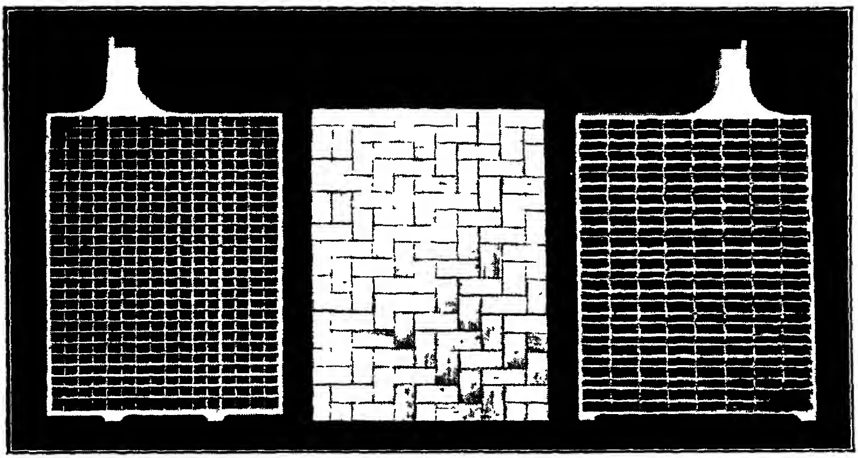


FIG. 19*b*.—Construction of Ace Battery.



Positive Plate. Lattice Separator. Negative Plate.

FIG. 19*c*.—Plates for Ace Battery.

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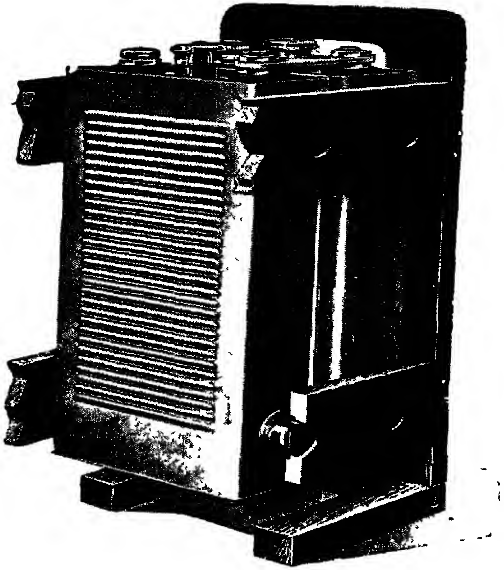

FIG. 19*d*.—Construction of Ionic Battery

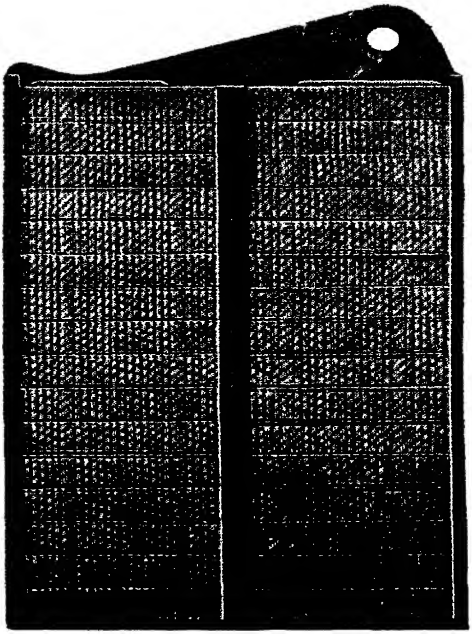

FIG. 19*e*.—Plate for Ionic Battery.

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ohm. On the other hand, the output per unit of volume or weight is somewhat smaller with the Ionic than with the Edison cell. It is claimed that the self discharge of the Ionic cell is even slower than that of the other types of alkaline cells. The present-day prices of Ionic cells are comparatively low, and if even the four years' life, which is guaranteed, can be obtained, the Ionic battery will be a very serious competitor of the older makes.

CHAPTER III

CONSTRUCTION OF ELECTRIC VEHICLES

Mechanical Construction of Electric Vehicles.—The construction of early electric battery vehicles is of very little practical importance. The following notes may, however, serve as a general guide to the work of the pioneers. The practical machine of the kind seems to have been made by Magnus Ward in 1886. This was a cab which was followed in 1888 by an omnibus and parcel van. The batteries used in these latter machines consisted of 56 E.P.S. cells each of 120 ampere-hour capacity. The whole vehicle weighed 3½ tons, and the battery 1·35 tons, the ratio of battery weight to total weight being 0·386, or 38·6%. This figure may be taken as representative of the early vehicles. Two 2½ h.p. Crompton motors were used, their efficiency at full load being 68%.

In 1895 the Jeantaud carriage was introduced; it had a battery of 38 Fulmen cells, the total battery weight being 850 kg. or 1870 lbs. The capacity of the battery was 300 ampere-hours. The complete vehicle weighed 3·15 tons, giving a ratio of battery weight to weight of vehicle of 0·267. The driving motor was rated 7 h.p. at 70 volts with an overload capacity of 14/15 h.p. The efficiency was stated to be 90%, and the fields could be separately excited for regenerative braking. The vehicle could do 25 to 44 miles per charge, and seems to have been very well designed for the period.

Those who are interested in the subject of the history of electric vehicles will find it well worth while to read the Cantor Lectures by Mr. Worby Beaumont in the *Journal of the Society of Arts* for 1896.

Mechanical Construction of Electric Vehicles.

General.—The *Chassis* construction of almost all modern battery vehicles is on the same general lines as that of heavy petrol machines, that is, the frame is of rectangular shape, and is built up of steel channels. This frame must be of very robust construction owing to the additional weight of the battery which has to be suspended from it. The stresses due to engine vibration and gear changing are, however, eliminated, and this serves to compensate to some extent for the higher static stresses.

Springing.—Full elliptic springing is generally employed on electric vehicles. The importance of good springing is very great in view of the comparative fragility of batteries of the lead type.

Wheels.—The classes of wheels used are very varied, Wooden Artillery Type, Pressed Steel Discs, and Cast Steel Wheels all being represented on the vehicles, which have come to notice of the writer.

Steering Gear.—Practically every type of steering gear known is in use on the makes of electric vehicles which are available. There is no conclusive evidence as to which is the best type.

Motors.—Series motors are generally used, but in one or two instances compound-wound machines have been tried with a view to getting regenerative electric braking. The number of motors per vehicle varies from one to four.

Controllers.—Drum controllers are standard in nearly every case. The principles of control used are variations of series resistance, series-parallel connections of field windings in the case of single motor vehicles, series-parallel connections of motors in the case of multi-motor vehicles, and series-parallel connection of groups of cells in the battery.

Transmission Gear.—The principal types in use may be classified as below, the order of classification being arbitrary.

(1) Chain drive from differential countershaft—one motor.
(2) Gear drive from a single motor.
(3) Chain drive from two separate motors.
(4) Gear drive from two motors.

Tyres.—Solid tyres are almost invariably used on electric vehicles. The grade of tyre has not been standardised, although this seems to have a very important bearing on the energy consumption.

Instrument Equipment.—British and American practice favours the use of ampere-hour meters to check the current consumption. Continental cars are usually fitted with an ammeter and a voltmeter for this purpose. An odometer is a standard fitting on all electric vehicles. The usual practice is to fit this on a wheel hub, although this is by no means the most convenient position.

In order to give a more exact idea of the construction of good modern electric vehicles, several machines will be described and illustrated in some detail. The examples chosen are typical of the best practice in their different classes, and the author has confined himself principally to vehicles with which he has personal experience, so as to be able to make comments on their performances.

Single Motor Vehicles with Chain Drive.—The vehicle chosen to represent this class is a chassis built by the General Vehicle Company at Tyseley, Birmingham. Vehicles with load capacities of from 2 to 5 tons are built on the same lines as that described.

Fig. 20 shows a G.V. 2-ton chassis. The chassis frame is of standard construction, with underslung battery boxes, motor and transmission gear. Semi-elliptic springing is used, and wooden artillery type wheels are standard.

The **steering gear** is of the pinion and sector type with a vertical steering column. This feature is somewhat unconventional and does not appeal to the average taste from the

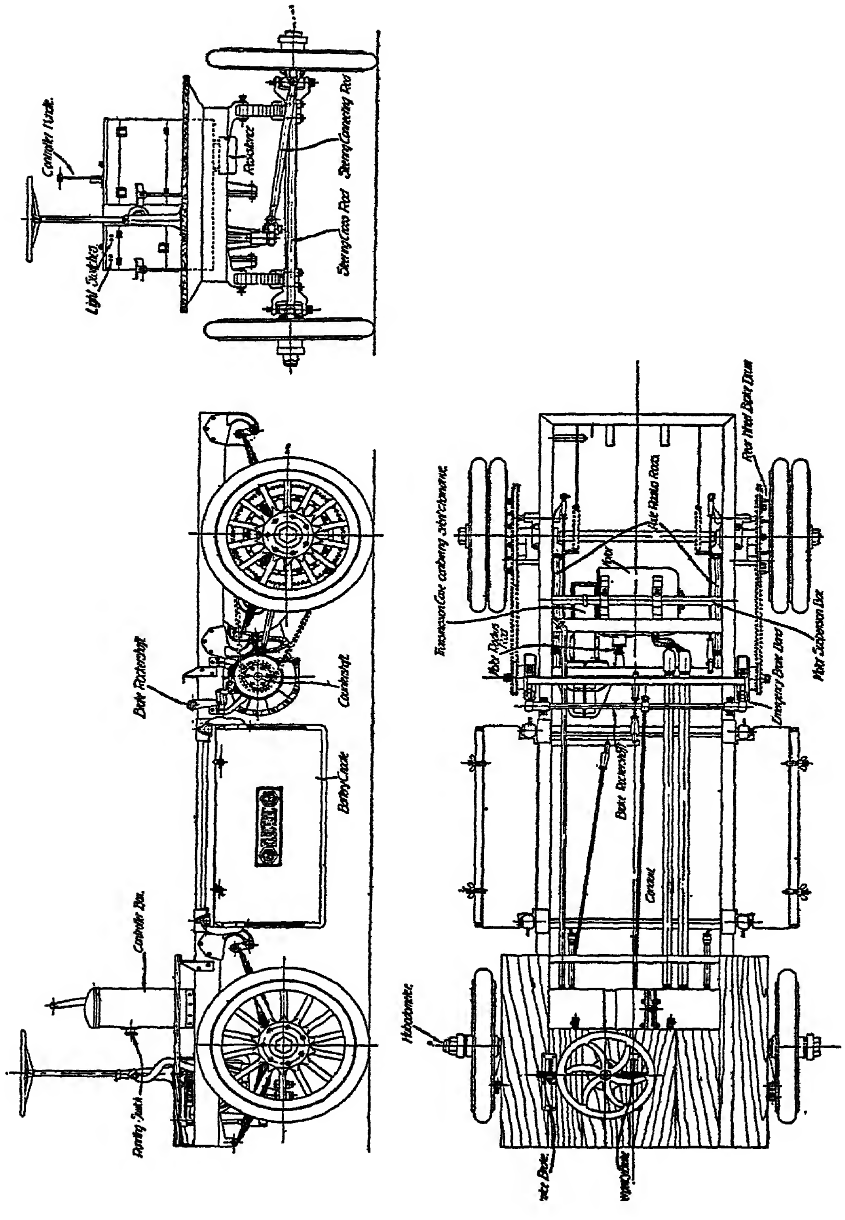
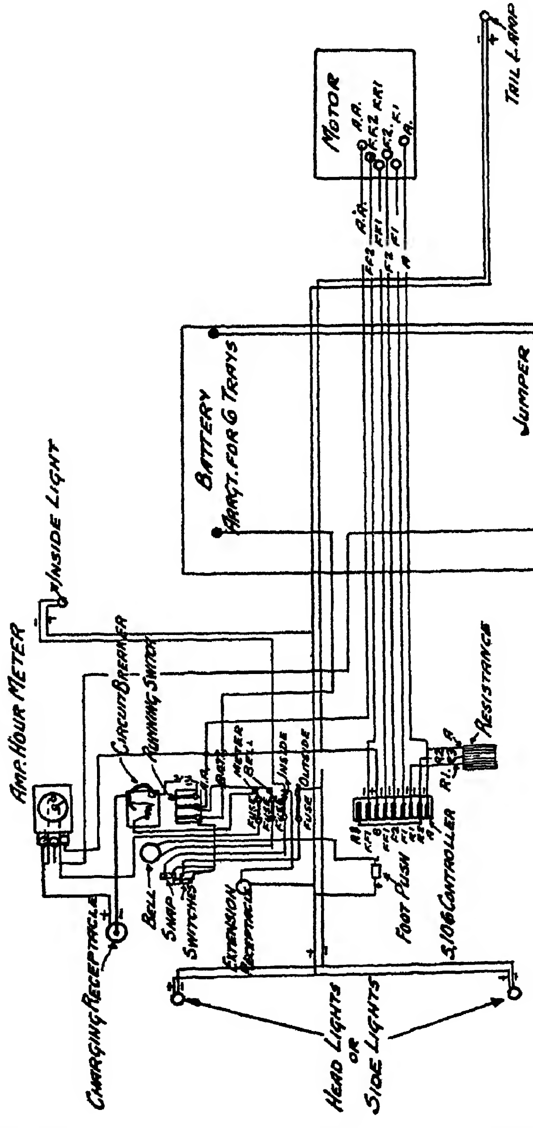


FIG. 20.—G.V. 2-Ton Chassis.

standpoint of appearance: the results are, however, perfectly satisfactory.



WIRING OF G. V. COYS ELECTRIC VEHICLE

FIG. 21.

Brakes.—Two sets of brakes are provided both of which are foot operated. The service brake acts on drums on the rear wheels. It is of the internal expansion type. The

emergency brake is of the external band type, and operates on drums on the countershaft.

Motor.—The motor is series wound, the field winding being in two sections for series-parallel connection.

Transmission Gear.—The transmission from motor shaft to rear wheels is in two stages. The first consists of a silent chain reduction gear from the motor to a countershaft. This part is totally enclosed. The second part of the reducing gear consists of open roller chains between the countershaft and rear-wheel sprockets. There is a differential gear on the countershaft.

Control.—The drum type controller is situated under the driving seat, and is operated by a handle on the driver's left hand. A complete wiring diagram of the controller, control resistance and motor is shown in Fig. 21. The control is done by combining variation of resistance with series-parallel connection of the field windings. Five forward and two reverse speeds are provided. The methods of obtaining the different speeds will be seen clearly in Fig. 21*a*. Forward speeds 1, 2, 3 and 4 are got by varying the resistance in the circuit with the fields in series. The normal running condition (speed 5) is with the fields in parallel. The two reverse direction speeds are got by variation of resistance, the direction of the current in the field windings being, of course, reversed.

From the above brief description it will be seen that the G.V. design is of the simplest possible type. No special features have been introduced, and success has been obtained solely by the accurate detail work which has given good overall efficiency, as well as reliability in operation. The author's personal experience of vehicles of this make has been extremely satisfactory. The only parts which have required replacement have been chains and sprocket wheels, controller contacts, brushes and shackle bolts. A point of considerable importance in connection with the maintenance of G.V. cars

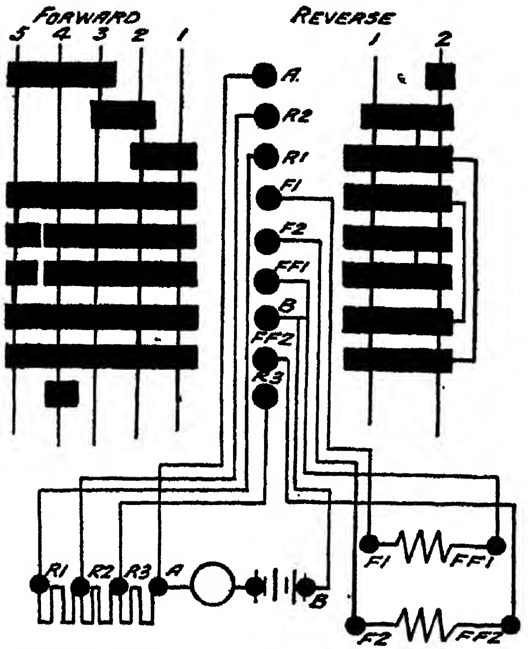


DIAGRAM OF CONTROLLER CONTACTS AND CONNECTIONS OF G.V. VEHICLE SERIES MOTOR

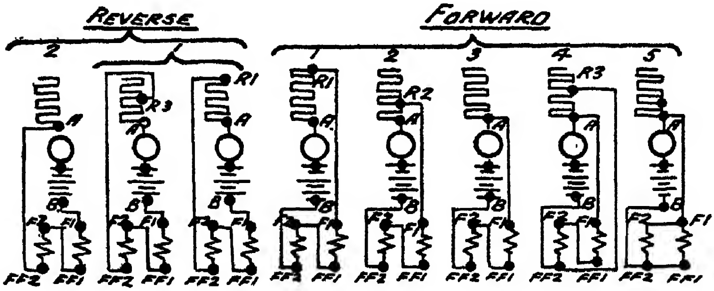


DIAGRAM SHOWING CONTROLLER CONNECTIONS IN G.V. SINGLE SERIES MOTOR VEHICLE

FIG. 21*a*.—Key to G.V. Control.

is that the completely enclosed differential has to be dismantled for refilling with lubricant. This need only be done at long intervals, but it should be remembered that if its renewal is too long delayed very serious damage may be done. Energy consumption and tyre wear are both light. This experience seems to be quite general, as is proved by the fact that the design has not had to be altered materially within the last ten years at least. The other single motor chain-driven vehicles which have been under the control of the writer have also been very satisfactory. The makes represented are, G.M., Edison, Detroit Edison, Lansden and Garrett, the last mentioned being especially noteworthy for convenience in handling and mechanical reliability.

Single Motor Vehicles with Gear Drive.—The obvious disadvantages of chains has led many designers to try to eliminate these, and yet retain the simple single motor system. The first example of this class chosen for description is the " Walker Balanced Drive Electric," built by the Walker Electric Vehicle Company, Slough. The design originated in America, where vehicles of this type have proved very successful.

Walker Balanced Drive Electric Vehicle.—A plan of a Walker balanced-drive chassis is shown on Fig. 22. The chassis frame, springing system brakes and steering gear are of quite conventional type, and do not require further mention. The motor and transmission gear are of very special design. These are shown in Fig. 23. From this figure it will be seen that the motor and differential are housed in the back axle. The drive to the road wheels is through a pinion wheel on the motor shaft, and two idler wheels to an internal toothed wheel. All the transmission speed reduction gearing is mounted in the disc type rear wheels. The whole chassis is so simple and the total number of parts so small that even a single motor chain-driven vehicle looks complicated in comparison. Disc wheels are used on the front. Fig. 24 shows the Walker control system. The controller is of the drum type; it is

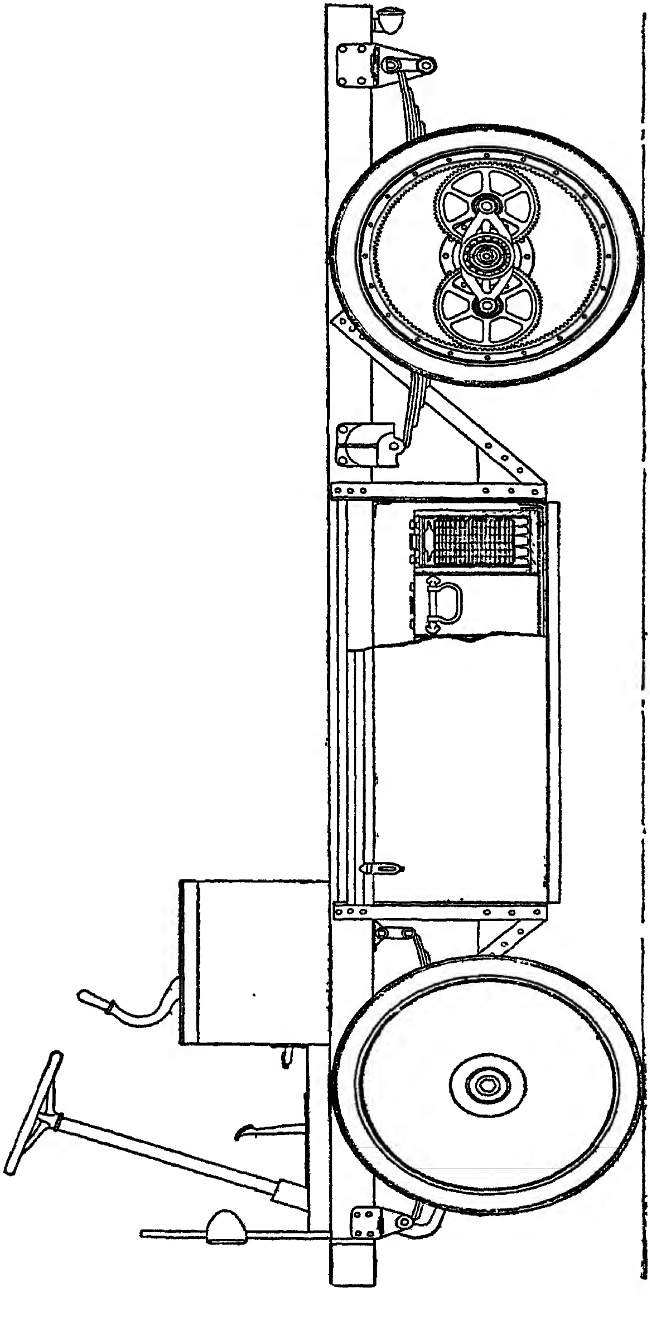


FIG. 22.—Walker B.D.E.V. Chassis.

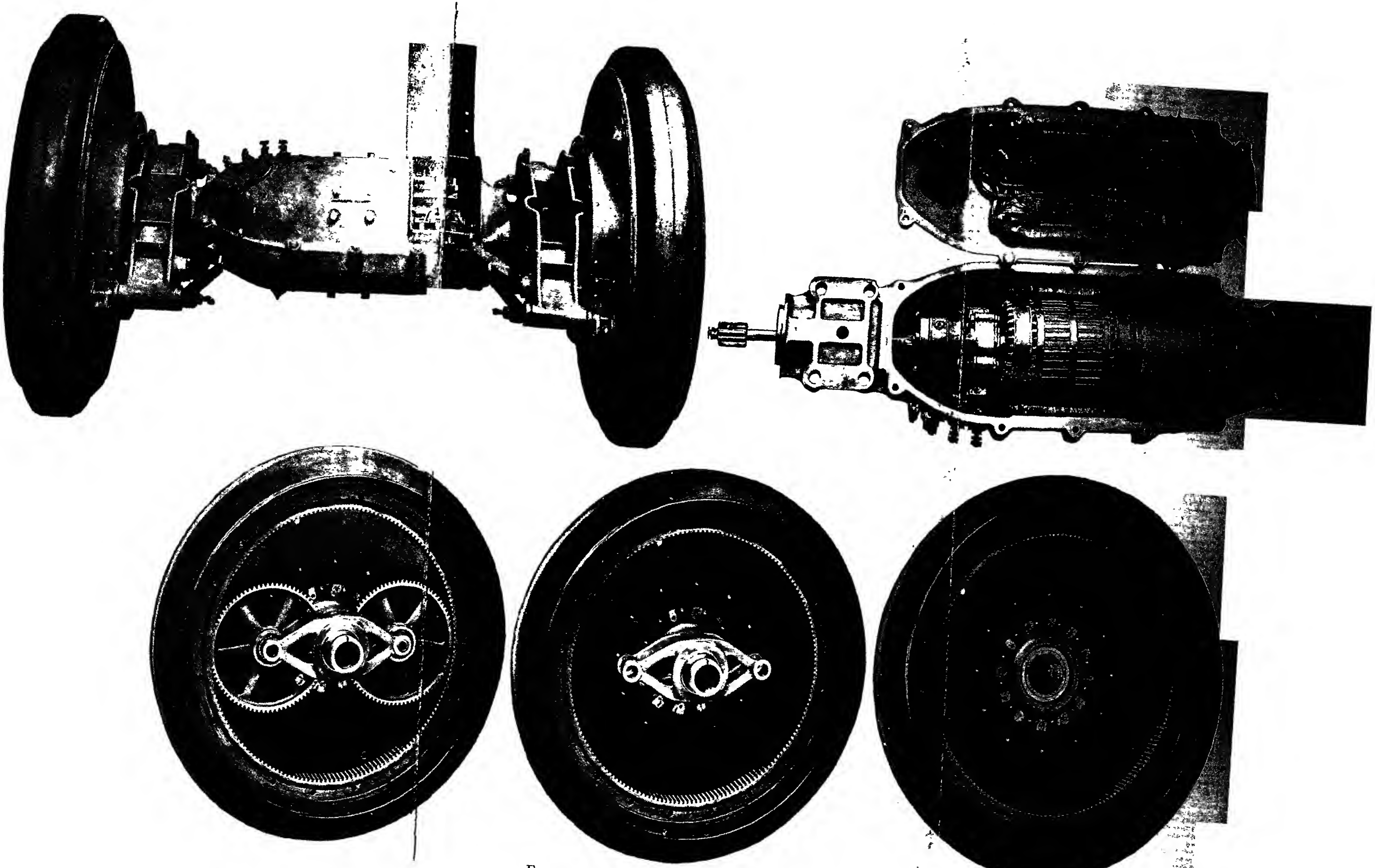


FIG. 23.—Walker Motor and Transmission Gear.

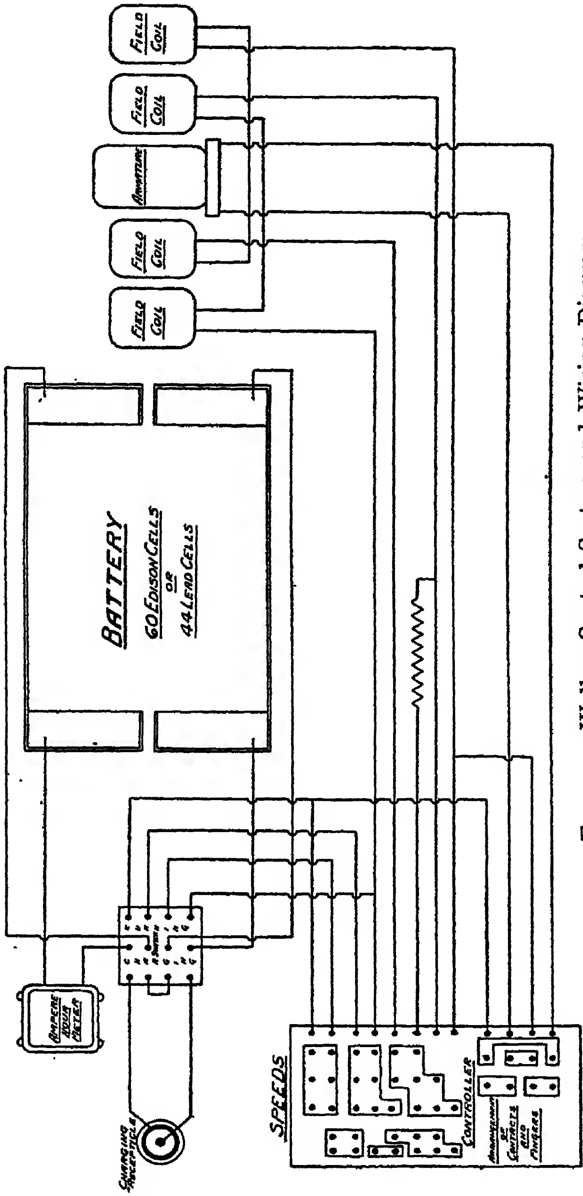


FIG. 24.—Walker Control System and Wiring Diagram.

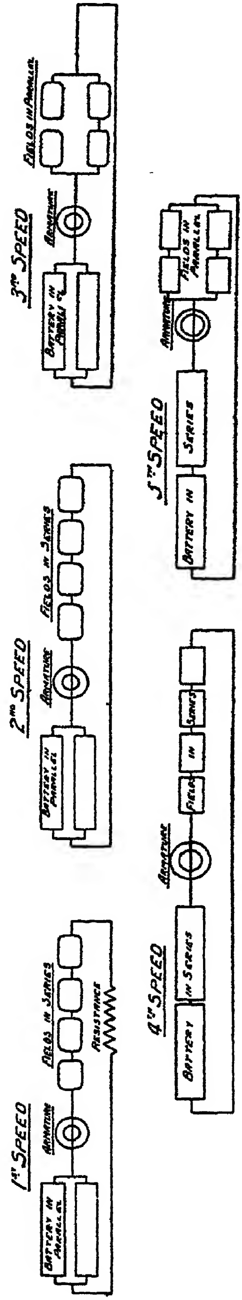


FIG. 24*a*.—Key to Walker Control System.

operated by a lever on the driver's right. The special feature of the Walker control is that the battery is in two sections, which are connected in parallel during the starting period, and in series for normal running conditions. The Walker Balanced Drive design eliminates the one serious weakness of the type previously described, since the whole of the transmission gear is completely enclosed. The Walker Company claims that the efficiency of transmission from motor to road wheel is 97%, which is quite as good as can be attained by a chain-driven vehicle under the best circumstances. The author has not been able to make exact tests on the transmission losses of vehicles, but his experience seems to show that very high efficiency is obtained with the balanced-drive system, and that the efficiency is maintained over a very long period. This view is based on the statistics of energy consumption of Walker vehicles on road tests, and during everyday running; it is also supported by the fact that there is very little wear on the gear wheels. It is sometimes asserted that the transmission system is very liable to be seriously damaged if the rear wheels are subjected to heavy side-thrust, such as is encountered when a vehicle is driven carelessly into a kerb. The author has not had any untoward experience of this kind, but the possibility of such trouble must undoubtedly be kept in mind.

The high cost of production of the components of the balanced-drive system is the only real disadvantage it has.

The Walker control system might possibly cause trouble due to the battery sections being unequally discharged; it has, however, a slight advantage in efficiency over purely rheostatic control, and the author's experience has been perfectly satisfactory, there being no signs of inequalities between battery sections. The wiring system and method of control employed is shown in Figs. 24 and *24a*.

The Garrett Electric Vehicle.—Garrett single-motor vehicles with chain drive are well known, and have given excellent service over a number of years. Messrs. Garrett

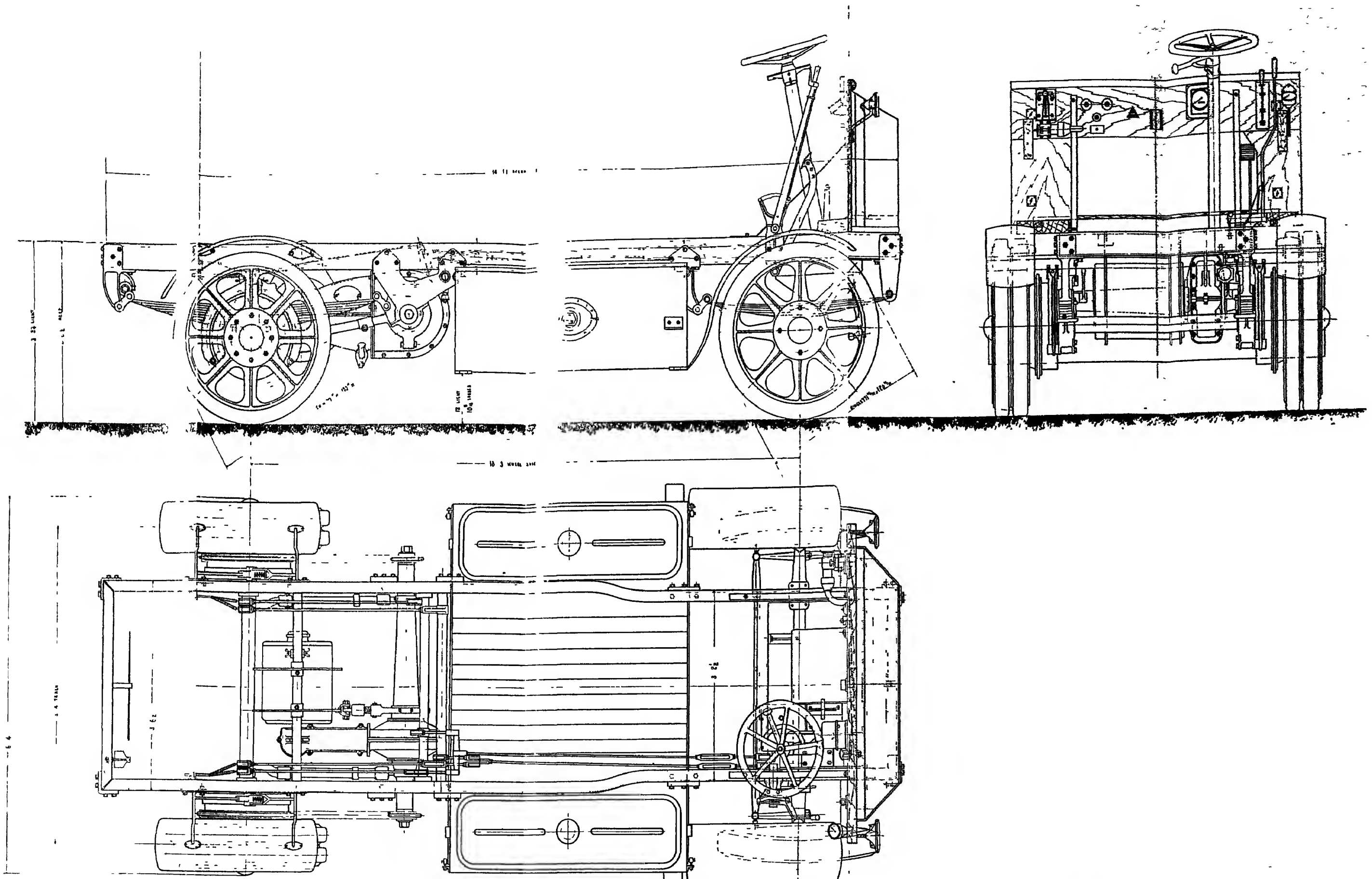


Fig 25 —Chassis Lay-Out of Garrett Electric Vehicle.

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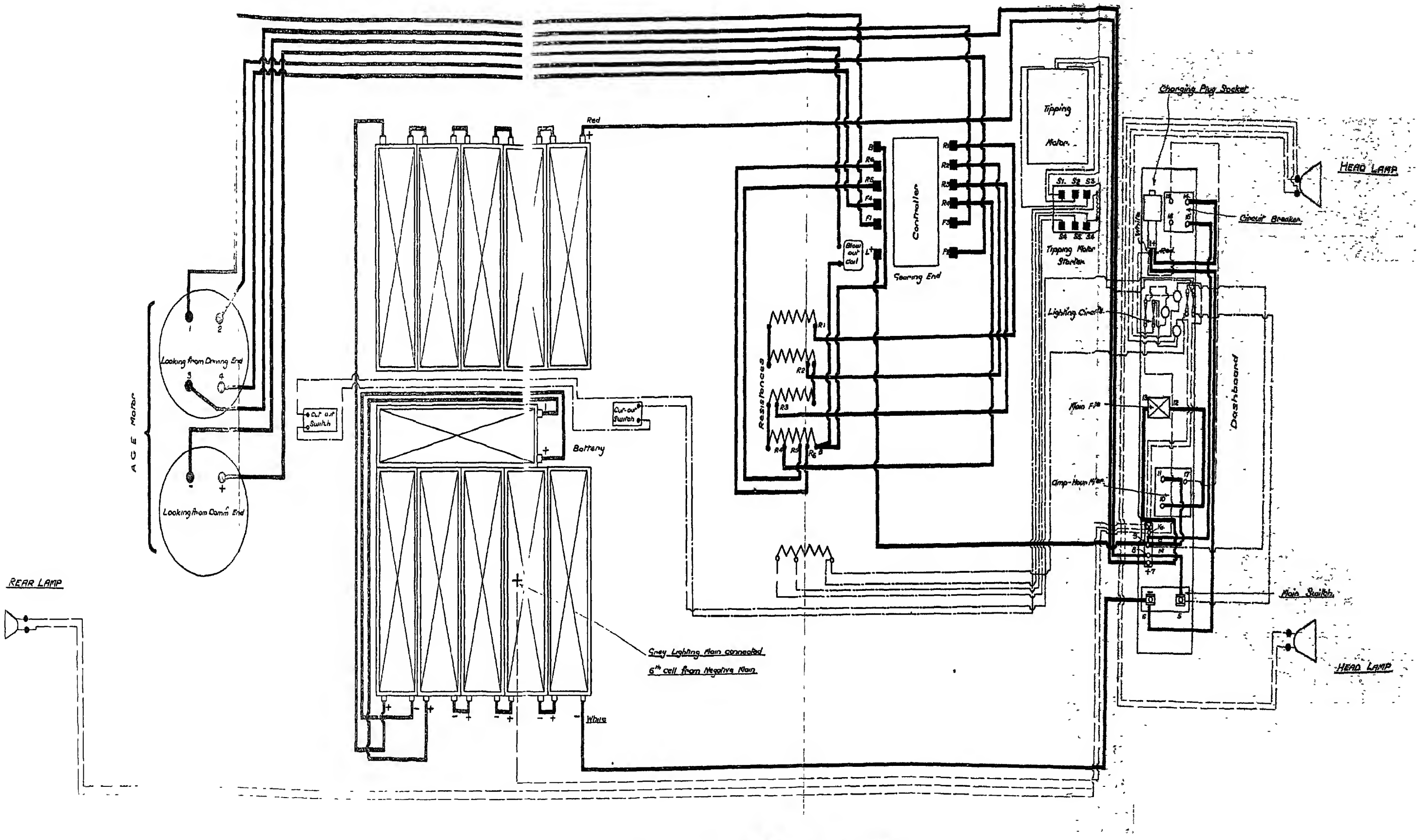

Connections Marked Thus ———— only used on Tipping Vehicles

FIG 26.—Wiring and Control System of Garrett Electric Vehicle

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have, however, recently put on the market a gear-driven vehicle of considerable interest. This vehicle is for comparatively light loads, say, up to 30 cwt., and is specially suitable for warehouse delivery work. The final driving system is by an overtype worm-gear on the back axle, which also contains the differential. The battery housing, springing brakes, and control do not differ materially from standard practice. The whole vehicle is noteworthy for its very robust construction, and for the high average speed which it can maintain. Fig. 25 shows the chassis lay-out of a Garrett chain-driven vehicle and Fig. 26 shows the wiring and control systems employed.

Clayton Vehicles.—Messrs. The Clayton Wagons, Limited, of Lincoln have recently introduced a series of electric vehicles which is of considerable interest. The general construction of the machines is exceptionally solid, and the 2½ ton refuse-collecting type is shown in Fig. 26*a*. The outstanding feature of this machine lies in the type of final drive used. Fig. 26*b* shows the rear axle and wheels. The axle is of the full floating type, and is driven by an overhead worm and wormwheel. The worm is of nickel chrome steel. It gears with a phosphor bronze wormwheel, which also carries the differential gear. The brakes are of the internal expanding type, and are of very ample capacity. The advantages of such a construction from a standpoint of maintenance are very obvious. The efficiency of worm transmission has been said to be somewhat low, but as it has been adopted by Messrs. Garrett, as well as by Clayton Wagons, Limited, the designs now available are doubtless greatly improved in this respect.

Vehicles with more than One Motor.—This class of vehicle has been developed with a view to reducing the energy consumption during the starting periods, and to eliminate the differential gear, which is essential with single-motor drive to two driving wheels.

The Orwell vehicle which has chain drive to the rear wheels

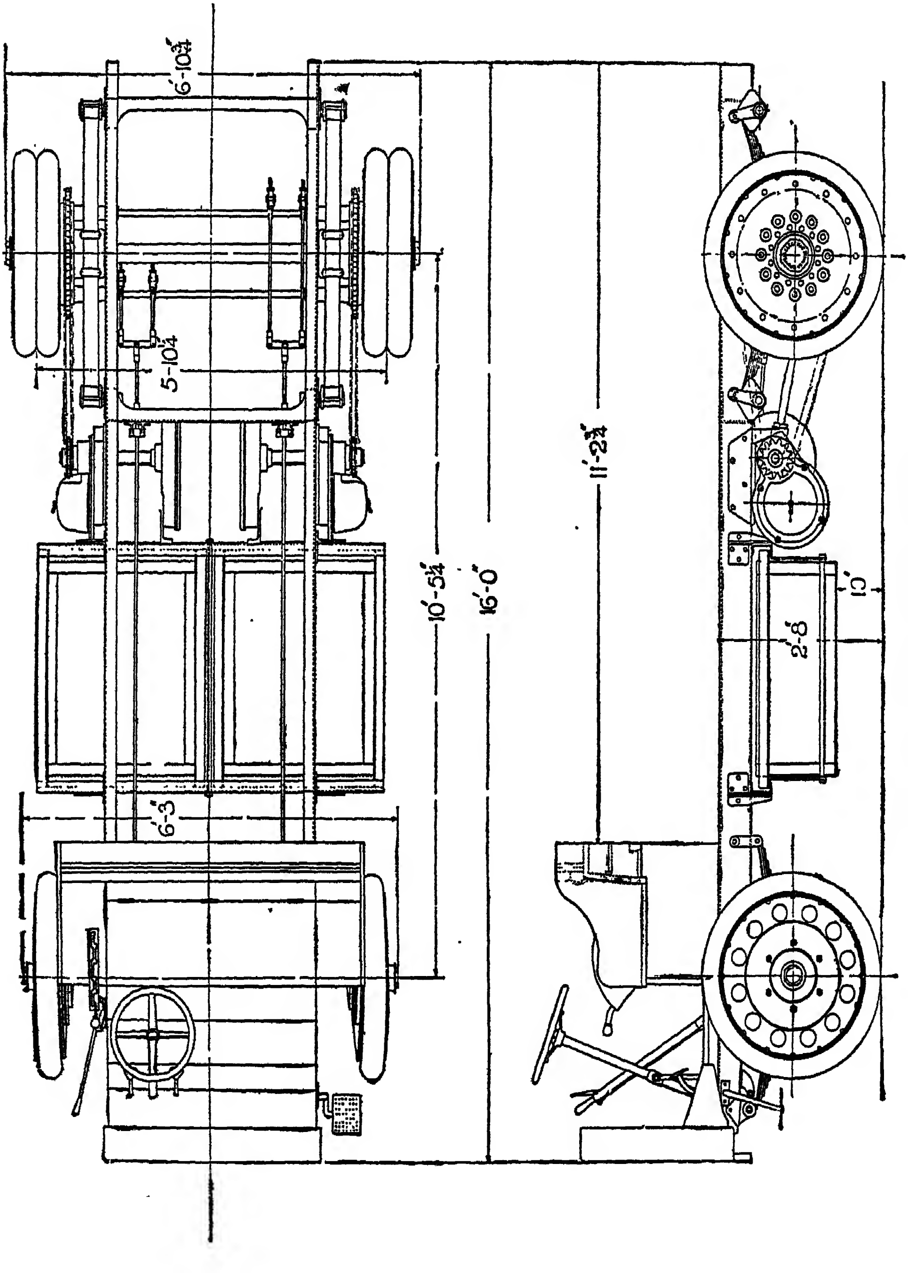

FIG. 27.—3½-Ton Orwell Chassis.

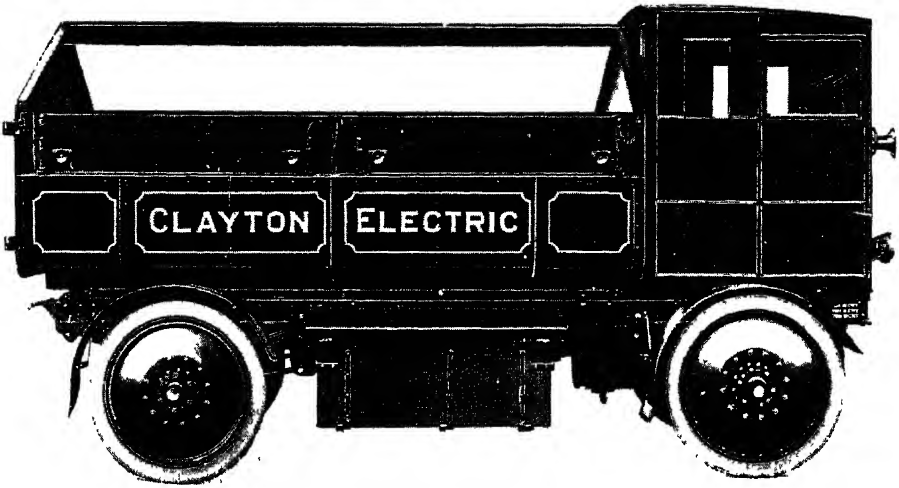

FIG. 26*a*.—The 2½-Ton Worm-Driven "Clayton" Vehicle with body suitable for Refuse Collecting.

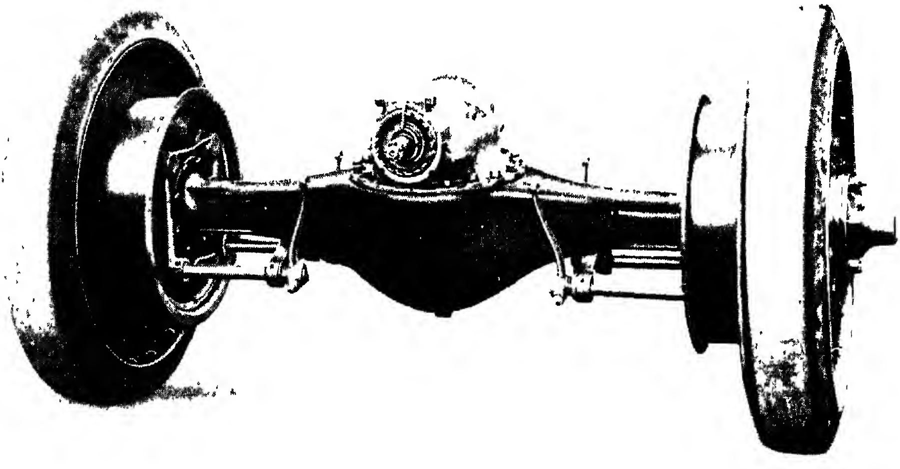

FIG. 26*b*.—A detailed view of the Hind Axle Unit, showing the overhead Worm and Worm Wheel and the simplicity of the whole design.

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is typical of its class. The mechanical construction of the Orwell vehicle, which is built by Messrs. Ransomes, Sims and Jeffries at Ipswich, is very strong. A diagram of a $3\frac{1}{2}$-ton chassis is shown in Fig. 27. The original points of the vehicle lie in the electrical equipment. The motors are of the compound wound type, the purpose of the special winding being

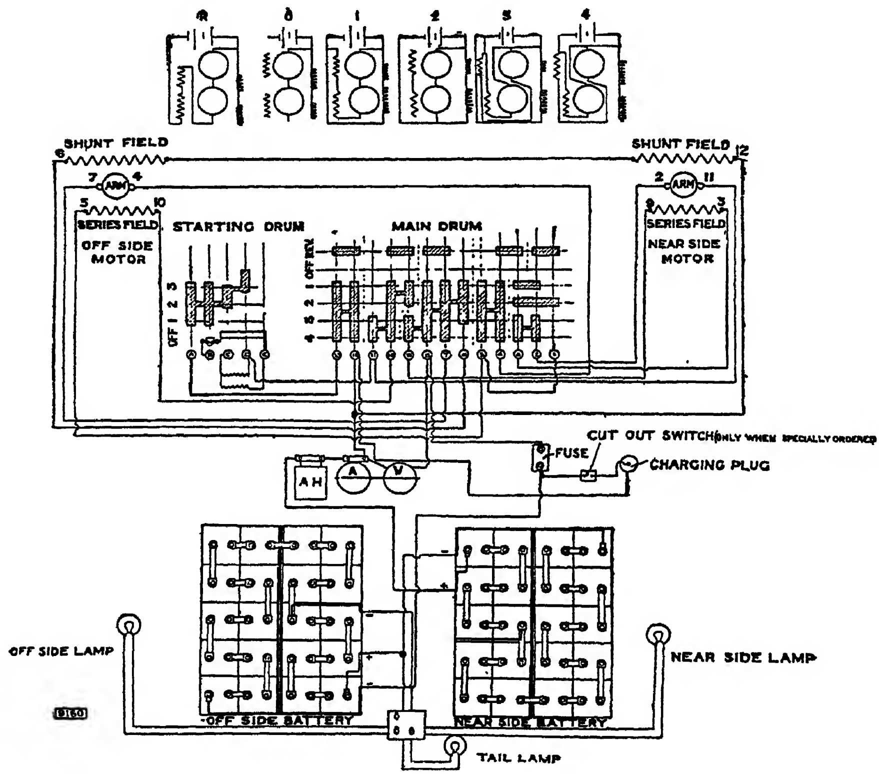

FIG. 28.—Wiring and Control System of Orwell Electric Vehicle.

to enable the motors to act as dynamos when circumstances permit; in this way some degree of regeneration of energy is obtained. The control gear is of a decidedly novel type. It consists of a hand-operated main controller, and a foot-operated auxiliary controller. The foot controller is used in much the same way as the clutch in a petrol vehicle; it is interlocked

with the main controller in such a way that the latter can only be operated when the former is depressed. The foot controller operates the resistance steps, and the hand controller the series-parallel ones. The wear due to arcing is practically wholly confined to the foot controller. The control scheme (Fig. 28) is due to Mr. Mossay, and is very convenient, especially because of the fact that it allows the driver full use of his hands for steering—a very considerable advantage, especially in the case of heavy vehicles.

The author has had experience of only one Orwell car—$3\frac{1}{2}$-ton tipping wagon. This machine has been satisfactory both mechanically and electrically except in the following respects. The battery capacity provided originally was inadequate, and the rated load capacity was much too conservative with regard to the exceptionally robust mechanical construction of the chassis.

The above Orwell vehicle is now fitted with a thin-plate battery of 400 ampere-hour capacity, and this has very materially increased the utility of the vehicle.

A minor trouble encountered lay in the difficulty of getting the main-controller fingers accurately adjusted. These fingers are of the roller type, and unless they are very carefully adjusted arcing is liable to ensue due to vibration.

Multi-Motor Vehicles with Gear Drive.—The Electromobile built at Leeds is the English prototype of the Commercial Car of America, and is probably the best known gear-driven multi-motor machine. The lighter vehicles have two motors which may drive either on the front or the rear wheels, the latter type being, in the author's opinion, by far the more desirable. Heavy types have a motor on each wheel. The Electromobile design is very original, and has evidently been produced with a view to getting extremely economical running so far as energy consumption is concerned. Series motors are used, and on 4-motor machines they operate in pairs, so that the control scheme is exactly the same whether there

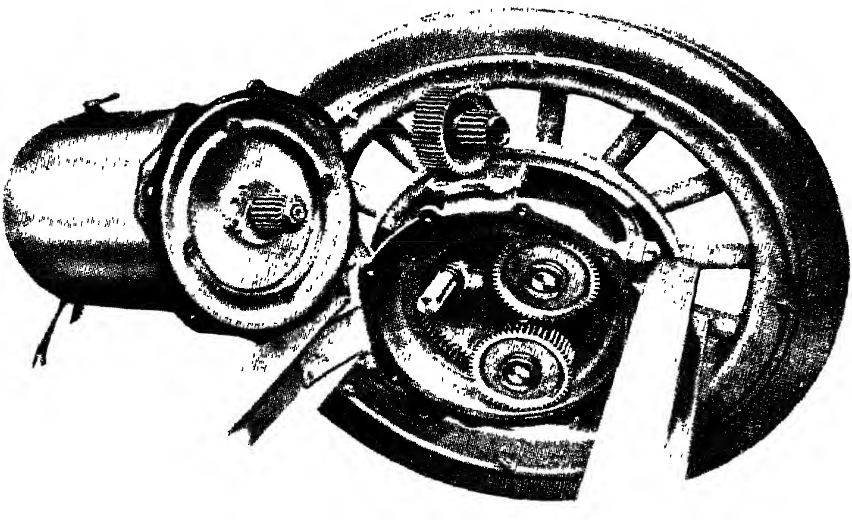

FIG. 29.—Reduction Gearing for Electromobile Vehicle.

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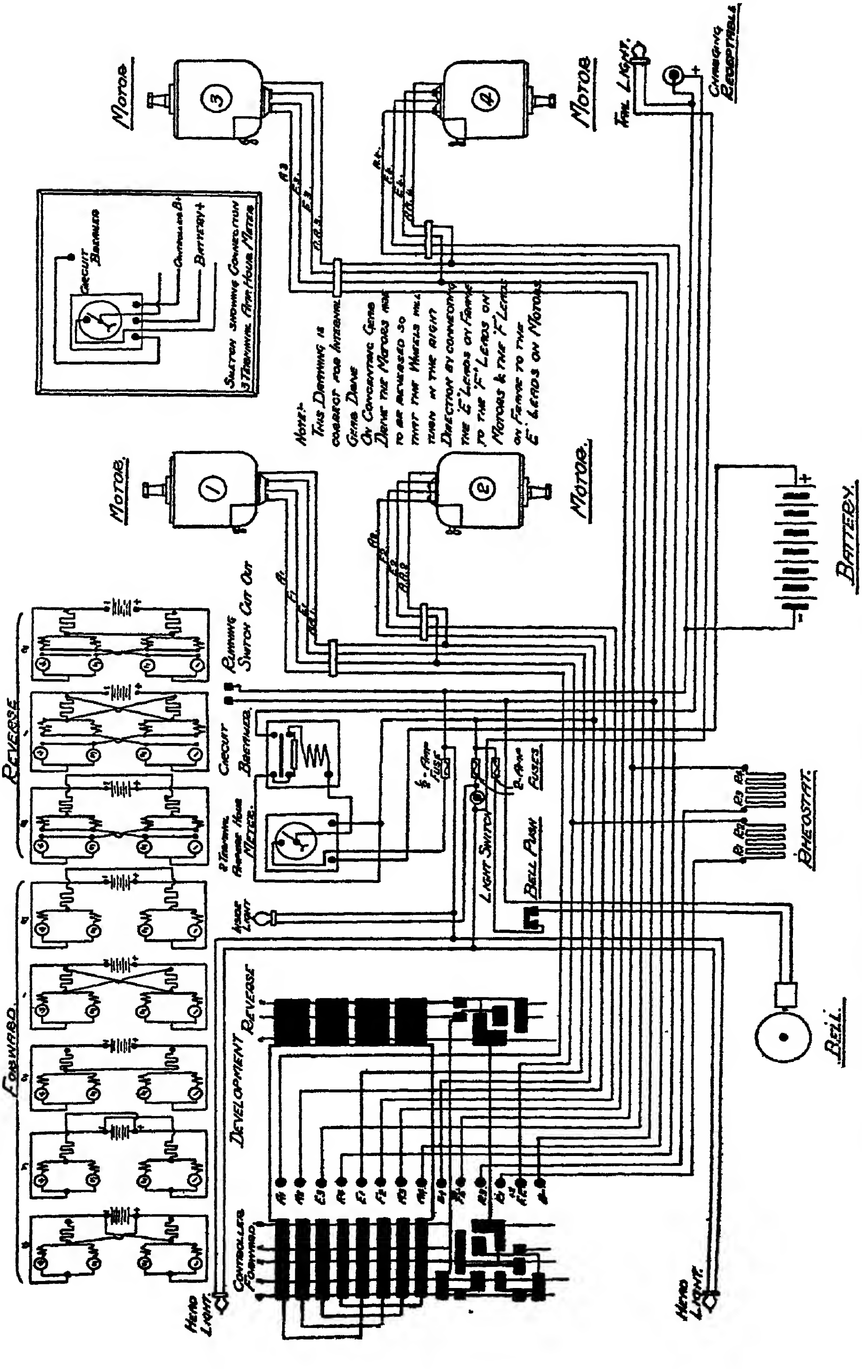

FIG. 30.—Control System and Wiring Diagram for a $3\frac{1}{2}$-Ton Electromobile Four-Motor Vehicle.

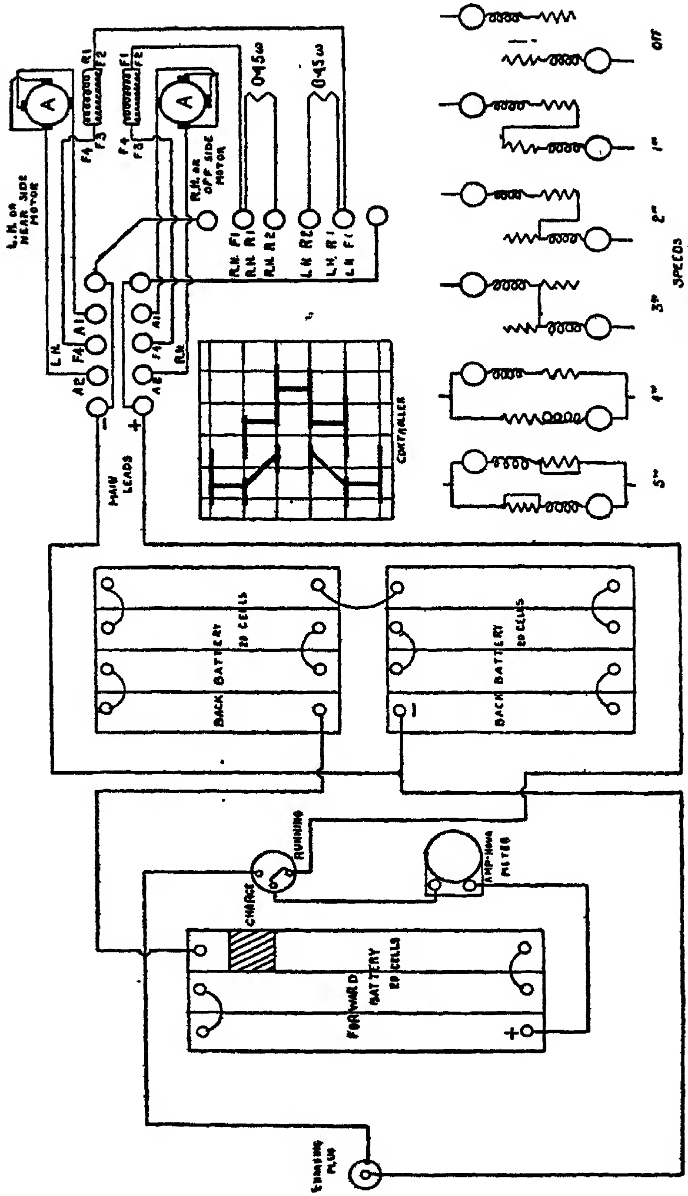

FIG. 32.—Control and Wiring Diagram for "Electricar" Vehicle.

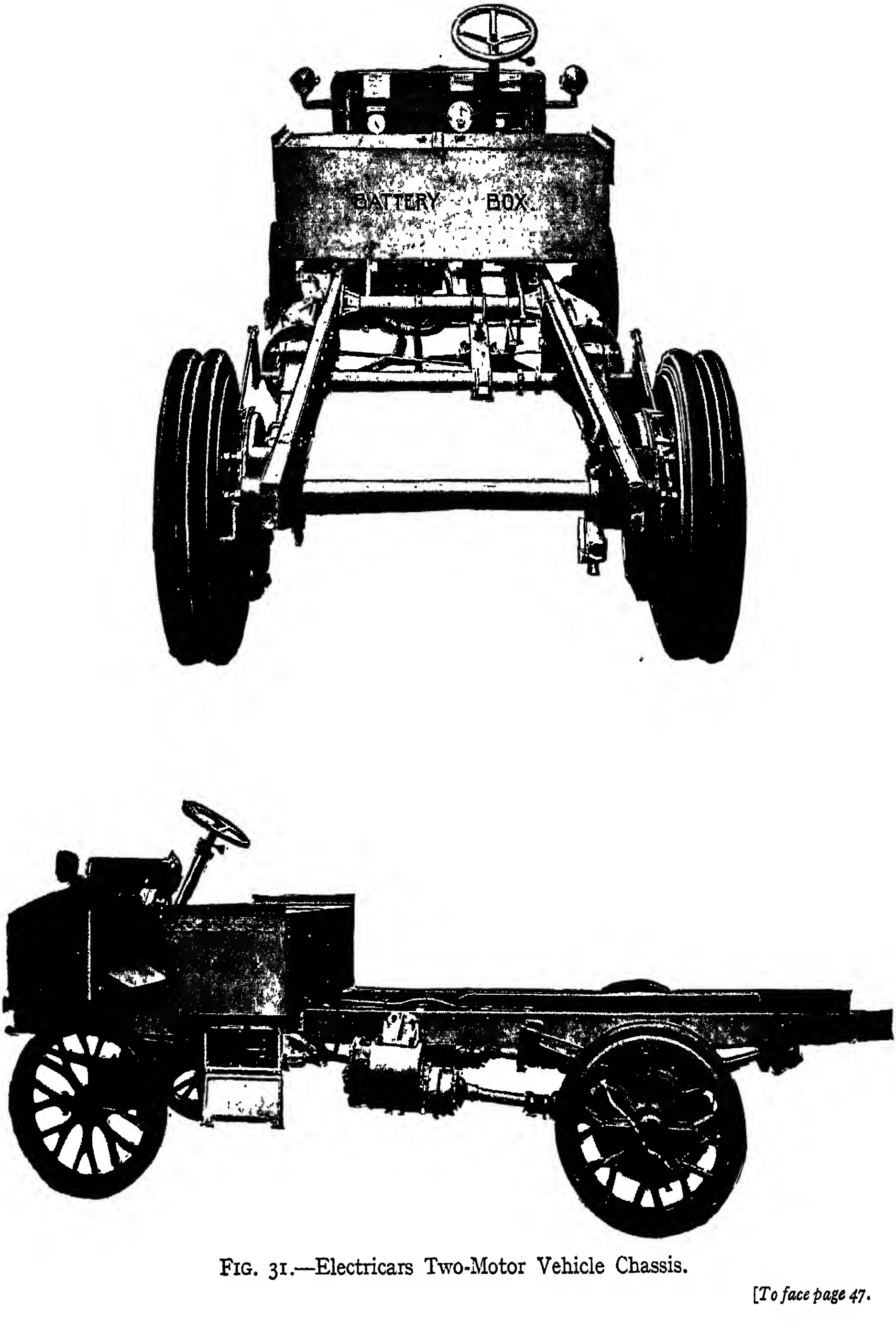

FIG. 31.—Electricars Two-Motor Vehicle Chassis.

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are 2 or 4 motors. Each driving unit consists of a motor, reduction gearing, and a road wheel. The reduction gearing is shown diagrammatically in Fig. 29. From this figure it will be seen that the torque of the motor is transmitted through three 2-speed polling pinions to an internal gear ring in the motor end casing. This part is the outstanding feature of the Electromobile design. The controller is mounted very conveniently on the steering pillar, and is operated by a small hand-wheel situated underneath and parallel to the steering wheel. The control system for a 3½-ton machine is shown in Fig. 30.

Running experience with Electromobile cars has revealed only one weakness, namely, a tendency for lubricating oil from the transmission-gear casings to get into the motors, and so damage the windings. The steering of vehicles with motors on the front wheels is also much stiffer than with ordinary designs. Although the unsprung weight is very great, the reliability of the gearing has proved excellent even on very rough service.

Electricars Limited, London and Birmingham, build a 2-motor gear-driven vehicle of novel design, the main features of which are shown in Fig. 31. The chassis frame longitudinal members are of wood reinforced by steel plates, and although this construction would be viewed unfavourably by many engineers, it has proved very satisfactory under very strenuous usage. The motors are not special in any way, being of the ordinary series type. They are mounted on the outside of the chassis frame, and the transmission is by inclined shafts. The speed reduction is done in two sections, one at the motor end of the transmission shaft, and the other at the driving wheels. The former is of the plain-gear and the latter of the bevel-gear type. The controller design is unique. The motor, battery and resistance connections are brought to fixed contacts on a flat plate, and the necessary changes are made by means of further connecting pieces mounted on a movable

plate. The standard control diagram is shown on Fig. 32. The battery-mounting is also novel, part being mounted in the front of the chassis in the position occupied by the engine in a normal petrol car and the remainder under the driver's seat. The wheels are of cast steel, and it is claimed that they are exceptionally light and strong. The ordinary running is excellent, the average speed being high for an electric vehicle, without an undue expenditure of energy. The steering and braking are also exceptionally good. The chief criticism to be made of the Electricar design is that the transmission system in the earlier models was unnecessarily complicated, the multiplicity of small parts giving rise to numerous troubles. Later machines have, however, been greatly improved in this respect, and the present production is extremely satisfactory.

CHAPTER IV

CHARGING AND REPAIR STATIONS—BATTERY CHARGING

Charging and Repair Stations.

THE great congestion prevailing in all cities has generally rendered it impossible to provide the space required for really convenient garages, and it is usually necessary to make provision for the maximum number of vehicles in a given area. In this respect, garages for all classes of vehicles are alike. The electric vehicle garage differs from the ordinary type only in the fact that it must be provided with suitable charging circuits and plant. The standard battery voltage for vehicle work is 70–90 volts, and the charging voltage required for such batteries is from 70 to 120 volts. The charging current per circuit depends on the capacities of the batteries to be charged and on the method of charging employed (constant current or constant potential).

The practical limits of maximum current per circuit may be taken as from 40 to 100 amperes. In a very few cases it is practical and economical to charge batteries direct from a supply network, but in most cases it is necessary to provide a special machine to transform the supply to the correct voltage and kind of current. The following are the principal classes of machines classified according to the type of supply available.

When the supply is direct current, but of unsuitable voltage, the required voltage transformation may be done by means of a motor generator set in all cases and under some conditions by means of a suitable balancer set. The motor generator does not require any special description, as it consists merely of a shunt or compound motor driving a D.C. generator. It

has the advantage of good voltage regulation, but the serious disadvantages of comparatively low efficiency, high cost and limited output. The balancer can be used most efficiently when the supply voltage is approximately a multiple of the required voltage. It has the advantages of high efficiency, compactness, and cheapness. Its only serious disadvantage is that some of the vehicles being charged are raised to the

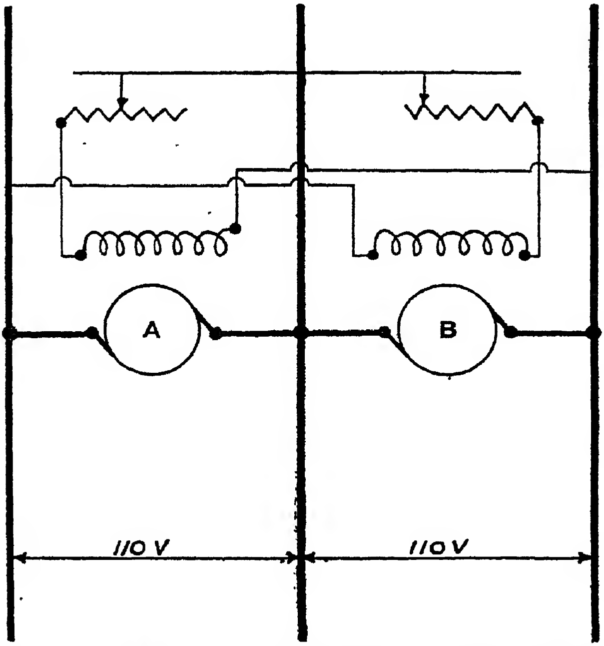

FIG. 33.—Diagram of Connections for 3-Wire Balancer.

maximum potential of the supply network. The comparative novelty of balancers in electric vehicle charging makes it necessary to give a somewhat more detailed description of this class of plant. A concrete example of a charging set for use on a 220-volt system is chosen for illustration of the system. Two similar 110-volt shunt-wound machines are connected in series across the mains. The shafts of the machines are directly coupled and their field windings are cross-connected as shown in Fig. 33. Batteries to be charged are connected

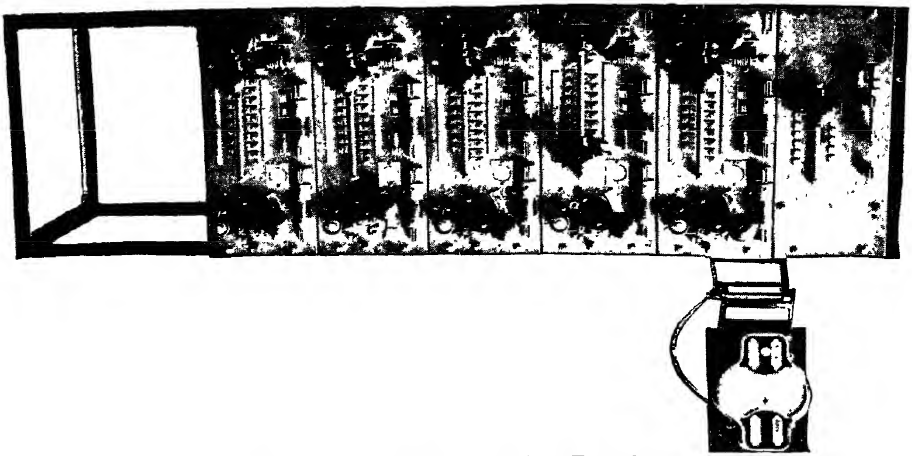

FIG. 35.—Igranic Charging Board.

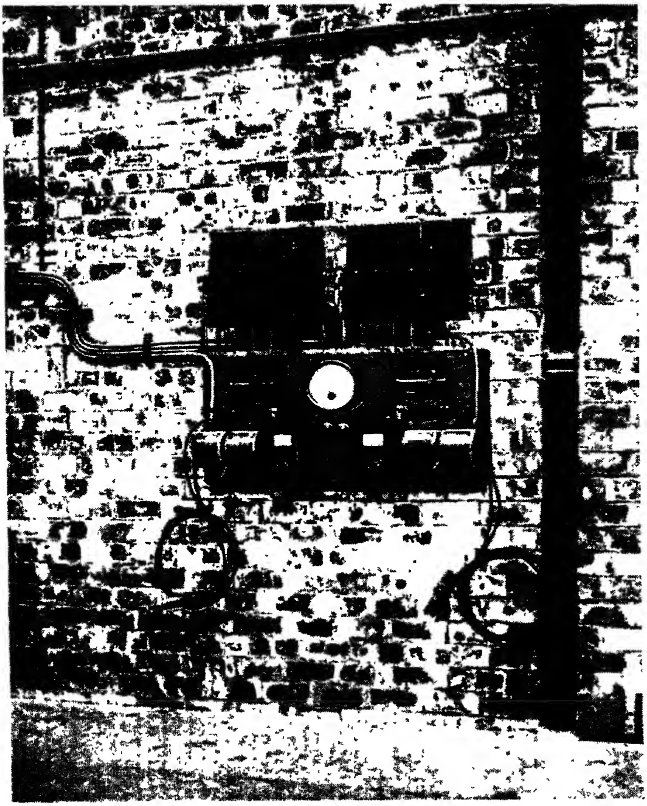

FIG. 36.—Two-Circuit Charging Board.

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either to machine A or machine B. The maximum current taken separately from one circuit depends on the capacity of the machines A and B, but provided the out-of-balance current is kept within the limits of the machines the total battery capacity which can be charged depends only on the capacity of the incoming 220-volt cable. With a 440-volt supply, four balancing machines would be used.

The size of the individual units forming the balancing set is determined by the capacity of the batteries to be charged. A detailed description of a complete installation which has been in satisfactory operation for a considerable period is given in the *Electric Vehicle* (October and December, 1922).

Transformation from alternating current to direct current can be done by means of motor generators, motor converters, or rotary converters. Motor generators are generally used because of the wide range of voltage regulation which can be obtained by means of the shunt or compound dynamo, but there is a very strong case for rotary converters where the A.C. voltage makes it essential to have a step-down transformer, no matter what type of machine is used for conversion from A.C. to D.C. The principal advantages of the rotary converter over the other types are higher efficiency and lower first cost and reduced floor space. The mercury vapour rectifier also provides a thoroughly reliable means of converting alternating to direct current, but it suffers from the serious disadvantage of comparatively low efficiency when the required voltage is low as is the case in battery vehicle work.

The charging stations with which the author has been associated have in all cases been mere adaptations of existing buildings, but a somewhat detailed description of one may be of some interest.

The building consists of a section of an old tramway depot, and the conditions were such that it was impossible to arrange for ingress or egress on more than one side of the building.

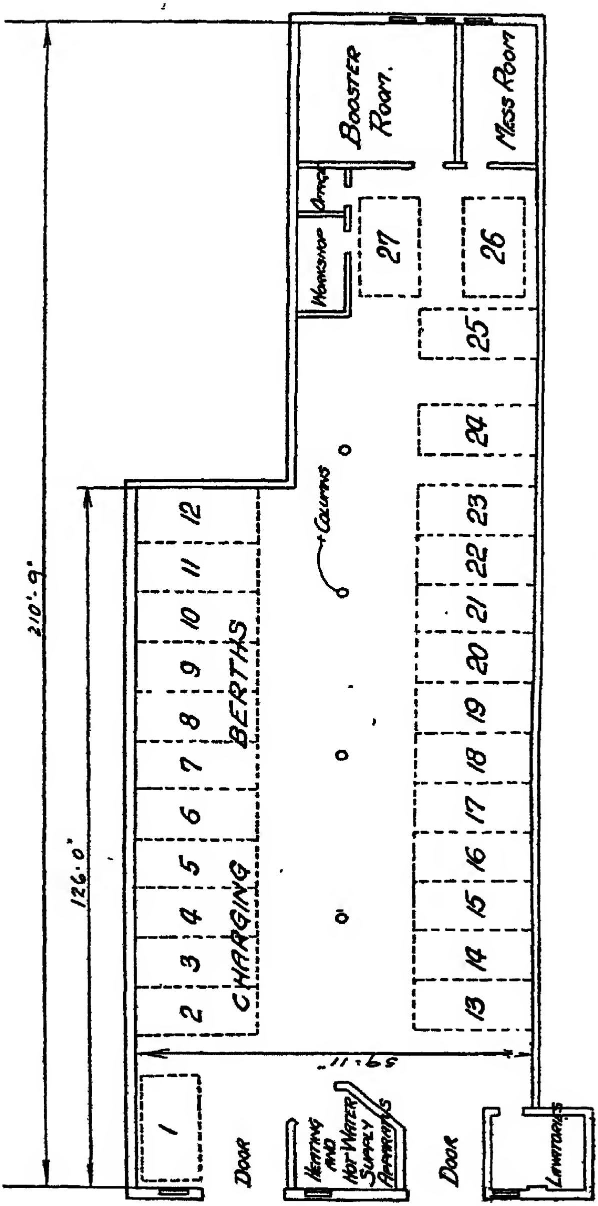

FIG. 34.—Plan of Whitevale Garage.

Apart from the entrance difficulty, the garage has proved quite convenient in practice. The floor space of the garage is sufficient for 27 vehicles arranged as shown in Fig. 34 (plan of Whitevale Garage). The charging plant consists of two motor generator sets each of 50 kw. capacity. The motors are 520-volt shunt-wound machines. The generators are also shunt-wound and the voltage range obtainable is 10 to 135 volts. An Igranic Charging Board (Fig. 35) is used, the present arrangement being for 5 circuits. The Igranic system concentrates all control switches, resistances and instruments at one point, thus enabling one operator to regulate the charging of a very considerable number of batteries. The wiring from the charging board to the charging plugs consists of 19/0·048 cable, the sectional area of each conductor being 0·034 sq. inch. The current density at maximum current is 2,000 amperes per sq. inch, and the voltage drop at this load 0·049 volt per yard run. The longest run is 55 yards and the maximum voltage drop in circuit is 5·4 volts.

An alternative, but in the author's opinion inferior arrangement, to the central charging board consists in having the regulating resistance and measuring instruments at the extreme end of the charging line. An arrangement of this type is shown in Fig. 36. The resistance unit in this case has a maximum value of 1·3 ohms, and can be reduced practically to zero by means of a sliding clip. The ammeter has a range of 0/100 amperes and is of the shunted moving coil type. An ampere-hour meter calibrated to read kilowatt-hours at the average charging voltage is used to measure the energy input to the battery.

Battery Charging.

General Requirements.—The essential requirement is a source of direct current of sufficient capacity, and means for regulating the voltage at the terminals of the battery which is being charged to the desired value. The different

types of machines and control gear are described under Garage Equipment. The most obvious method of charging a battery is to keep the charging current constant at the rated value during the whole charging period. This procedure is known as the *Constant Current Charging System.* When this method is used the impressed voltage must be gradually raised to compensate for the rising voltage of the battery which is being charged. The practical procedure with lead batteries is to continue the constant current charging at normal rate until all cells are gassing freely. The current is then reduced to about 40% of its normal value, and is maintained at this until the charge is complete. For lead batteries the best bus-bar voltage is about 2·5 volts per cell, and if a series rheostat is used it should be sufficient to cut down the current to about 40% of the normal value. Thus, with a 44-cell vehicle battery of 225 ampere-hour capacity, the bus-bar voltage would be 110 volts. The resistance would be built to carry 45 amperes and its ohmic value would be, say, 2 ohms. The most important point in the charging from the standpoint of safeguarding the cells is to ensure that the temperature does not exceed the safe limit of 43° C. or 110° F. Nickel iron batteries require about 7 hours' charging at normal rate. The charging is continued until the voltage per cell reaches about 1·85 volts. The voltage is the only indication of the state of charge in cells of this type, since the specific gravity of the electrolyte is constant throughout the whole charge and discharge cycle.

The limiting temperature of the electrolyte in nickel iron cells is 46° C. (115° F.).

The system described suffers from the serious disadvantage that the E.M.F. applied to the battery terminals must be continually varied. The *Constant Potential System* has been devised to overcome this drawback. In this system the applied voltage is kept constant throughout the charge. The initial current is greatly in excess of the normal rate, but it gradually decreases as the voltage of the battery which is

being charged increases. With lead acid batteries, the maximum allowable voltage to be applied to a battery is 2·4 volts per cell. The minimum is 2·2 volts per cell. (For nickel iron batteries 1·7 volts per cell is required.) The best means of reducing the bus-bar voltage to the desired value is to introduce counter E.M.F. cells which consist of unformed lead plates in dilute sulphuric acid. The E.M.F. of each cell is approximately 2·3 volts and is practically independent of the current. The constant potential system will give the correct charge to a battery in any state of discharge without causing any excessive rise in temperature, and without the cells reaching the free gassing stage. The time required to charge a battery which has been completely discharged will be about 60% of the normal time of discharge, *i.e.* if the normal time of discharge is 5 hours the time required for a constant potential charge will be 3 hours.

In everyday working it is found that the charging current is liable to vary very considerably, due to slight changes in bus-bar voltage and battery temperature. For this reason, and also because the high initial charging rate makes it necessary to have a larger charging plant than would otherwise be needed, it is customary to have a small resistance in series with the battery which is being charged. This gives a compromise between the constant current and constant potential systems, which is very convenient; it must, however, be remembered that the use of resistances must be reduced to a minimum in order to avoid the waste of electrical energy entailed.

Boosting Charges.—If the working conditions of a battery are such that one ordinary charge per day is insufficient, it is customary to give short high rate charges at any convenient time. Such charges are known as Boosting Charges. Boosting has been widely recommended by many battery-makers and is often resorted to. The author is, however, of the opinion that it is as a rule much better to work batteries regularly without giving them boosting charges, as in this way they last

much longer than otherwise. It is, however, purely an economic question, as in some cases it obviously pays to get more work out of a truck even at additional battery cost.

Equalising Charges for Lead Batteries.—The individual cells of a battery have, unfortunately, not got identical characteristics, so that in the course of time their states of charge begin to differ. For example, after a complete ordinary charge some cells may be slightly lower in specific gravity than the others, and the differences inevitably become more pronounced after each charge and discharge cycle. In order to establish equality throughout a battery, it is given a long, slow charge at regular intervals, the object being to get the whole of the active material in the plates to its correct condition. Equalising charges are made about once a month, or, say, every 30 cycles. It is, of course, self-evident that equalising charges alone can do no good to cells which are mechanically defective, so that any cells which fail to reach the normal specific gravity after this treatment must be opened up, examined and repaired before they can give their rated output. The frequency with which equalising charges must be given and the amount of divergence of specific gravity is one of the best indications as to whether a battery is good or bad from a chemical standpoint. Equalising charges are also very valuable for detecting short circuits between plates due to faulty separators, accumulations of sediment, growth of plate frames, etc.

Battery Records.—It is customary for battery manufacturers to give a guarantee for their batteries over periods of from 20 to 24 months. With most makers, the guarantee is made on condition that the battery is used and charged under certain specified conditions, and to ensure that these conditions are being fulfilled the makers insist that accurate records of the performance of their batteries should be regularly supplied to them. The data demanded by most makers are—each discharge and charge of battery in ampere-hours, and specific gravities and temperatures of typical cells known as pilot cells

Exide-Ironclad FORTNIGHTLY RECORD. *Commencing* 1st February 1923.

User: Glasgow Corporation Electric Department. *Address:* 75, Waterloo Street.

Battery of 42 *Cells,* *Type:* I.M.V. 10 (21 plates per cell). *Battery No.:* 8507.

Registered No. of Vehicle: G.A. 3367. *Type:* 5 T. Tip. Wagon. *Date battery installed:* 7 Jan., 1923.

DAILY READINGS.

Date. 1923. Feb.	Mileage Indicator Reading.	Miles Run.	Regular Charges. Amp.-Hour Meter Readings. After Discharge.	After Charge.	Pilot Cell No. 7. Before Charge. Sp. gr.	Temp.	After Charge. Sp. gr.	Temp.	Supplementary Charge No. 1. Amp.-Hour Meter or Hydrometer Readings. Before.	After.	Supplementary Charge No. 2. Amp.-Hour Meter or Hydrometer Readings. Before.	After.
1		22	150	Zero	1205	74	1275	81	180	50		
2		23	190	,,	1190	76	1275	79	110	Zero		
3		7										
4	Sunday		100	,,	1195	76	1275	76				
5		21	130	,,	1200	72	1275	76	170	40		
6		15	60	,,	1220	70	1275	78	105	Zero		
7		20	190	,,	1180	74	1275	76	100			
8		18	120	,,	1200	70	1275	74				
9		19	140	,,	1195	76	1275	76	140	40		
10		6		,,								
11	Sunday		90	,,	1240	70	1275	74				
12		18	190	,,	1200	70	1275	74	110	40		
13		16	130	,,	1200	68	1275	76	160	80		
14		21	180	,,	1190	76	1275	80	100	20		
15		21	160	,,	1200	74	1200	82	100	20		

REMARKS.

Give dates of Equalising Charge and note unusual conditions, or attention to battery.	Abbreviations. C.T.U.=*Cells topped up.* N.C.G.=*No charge given.* N.I.S. =*Not in service.* M.I.D.=*Mileage indicator defective.* M.E.=*Mileage estimated.* A.A.=*Acid added.*

EQUALISING CHARGE READINGS.

An Equalising Charge is to be given after every five or six cycles of charge and discharge, i.e., weekly for a vehicle on constant service. Commence to record hourly readings when current is reduced to the "Equalising Charge" rate.

No. 1. Given on 11 Feb., 1923.

Time.	Amps.	Battery Voltage.	Pilot Cell No. 7. Voltage.	Sp. gr.	Temp.	Remarks.
4 p.m.	11	102	2·6	1275	74	
5 ,,	,,	,,	,,	,,	,,	
6 ,,	,,	,,	,,	,,	,,	
7 ,,	,,	,,	,,	,,	,,	
8 ,,	,,	,,	,,	,,	,,	

No. 2. Given on ....192......

INDIVIDUAL CELL READINGS.

To be taken monthly towards the end of an Equalising Charge. For batteries containing more than 60 cells, use Form 973 instead of this space.

Readings taken on 4 Feb., 1923.

Charging Current when readings were taken..................*Amps.*

Cell No.	Sp. Gr.	Volts.	Cell No.	Sp. Gr.	Volts.	Cell No.	Sp. Gr.	Volts.
1	1275	2·5	21	1255	2·4	41	1280	2·6
2	1270	,,	22	1275	2·5	42	1275	,,
3	,,	,,	23	,,	,,	43		
4	1275	,,	24	,,	,,	44		
5	,,	2·6	25	1280	2·6	45		
6	1280	,,	26	1275	2·5	46		
7	1275	,,	27	,,	,,	47		
8	1280	2·5	28	1265	2·6	48		
9	,,	,,	29	1275	,,	49		
10	,,	2·6	30	,,	2·5	50		
11	,,	,,	31	,,	2·6	51		
12	1265	,,	32	,,	,,	52		
13	1275	2·5	33	1265	,,	53		
14	1285	2·6	34	1275	,,	54		
15	1275	,,	35	[illegible]	[illegible]	[illegible]		

A copy of this report to be forwarded on completion to:— THE CHLORIDE ELECTRICAL STORAGE CO., LTD., Clifton Junction, MANCHESTER.

at the beginning and end of each ordinary charge. A complete record sheet for an Exide Ironclad Battery is given with all figures filled in, so as to provide the reader with an actual instance of such records (Fig. 37). Similar, but somewhat less detailed, sheets are used by the other battery manufacturers. Nickel iron batteries are much more robust than lead acid batteries, and as a result of these users are liable to keep no records of their work. It is, however, well worth while to record all necessary information. A sample record sheet for an Edison Battery is given to show what is required (Fig. 38). The cost of record keeping is quite an important item in the maintenance of electric vehicle batteries, especially where the batteries and battery containers have not been standardised and designed to give convenient access to all cells.

Edison Battery Record. Commencing 25th May, 1924. *Glasgow Corporation Electricity Department. Mathieson Road Garage. No. of Vehicle,* 20. *Type* 2. *T. Tip. Wagon. Date Battery Installed,* 11/5/21. *Week ending* 31*st May,* 1924.

	Sunday.	Monday.	Tuesday.	Wednesday.	Thursday.	Friday.	Saturday.
Regular Charges A.H. . .	236	318	291	300	291	281	—
Supplementary Charges A.H. .	—	54	100	—	63	—	—
Discharge A.H. .	—	230	270	190	200	270	170
Miles Run . .	—	23	26	20	20	32	20
No. of Journeys .	—	4	5	2	3	5	2
Remarks . .							
Average Amp. Hours/mile .	—	10	10·4	9·5	10	8·4	8·5

FIG. 38.—Edison Battery Record.

CHAPTER V

OPERATING EXPERIENCE WITH ELECTRIC VEHICLES—AND TRANSPORT WORK OF AN ELECTRICITY SUPPLY UNDERTAKING—CONCLUSIONS DRAWN FROM GLASGOW EXPERIENCE.

Operating Experience with Electric Vehicles.

THE following is a general outline of the author's experience with the above fleet of electric battery vehicles operating in the city of Glasgow. It is feared that much of the information may be insufficiently detailed to be of real value to experts, but it is hoped that it will be of sufficient interest to justify inclusion, especially since the drawbacks as well as the advantages of the vehicles and batteries are recorded. The subject will be dealt with under the following headings: Mechanical Construction of Vehicles, Electrical Equipment (Motors, Wiring and Control Gear), Batteries, Accessories.

Mechanical Construction.—The mechanical parts of electric vehicles are subjected to the same stresses as those of any other type of machine, so that whether they withstand these stresses well or badly depends entirely on the capacity and experience of their builders. Dealing first with the main chassis members, only one failure has occurred, so that in this respect most designs seem to be very adequate.

Channel iron construction is practically standard, but one manufacturer has adopted wooden main members strengthened by side plates on 2-ton vehicles with very marked success.

Springs.—Cases of complete breakage have been very infrequent, but it is often necessary to have springs reset. The causes of this trouble are probably overloading of the vehicles

combined with faulty material. In one type of machine much trouble arises due to failure of the centre bolts of the rear springs. In this case the centre bolts were called on to transmit the driving force from the rear axle to the chassis, so that very careful construction was necessary to ensure satisfaction.

Transmission Gear.—The following types of transmission gear are represented in the fleet of vehicles under consideration.

Chain drive from a single motor.
" " " two motors.
Gear drive from a single motor.
" " " two or four motors direct to roadwheels.
" " " motors through shafting.

Chain drives have in all cases given very good satisfaction. The chains and sprocket wheels are exposed and somewhat rapid wear is inevitable, but it is always possible to foretell fairly accurately when it will become necessary to renew any part, so that there is practically no chance of trouble occurring during the ordinary running of a vehicle. The life of a chain cannot be stated very definitely, as the qualities of material used by the different makers and the stresses to which the chains are subjected vary greatly. An average life of 30,000 miles was obtained from American chains purchased in 1913 to 1915 and used on vehicles of from 1- to $3\frac{1}{2}$-ton capacity. On heavier vehicles, a life of 5,000 miles per chain is all that has been obtained, but the duty in this case was extremely severe and the chains were much worn by abrasion.

It is, of course, evident that much depends on the care with which chains are used, and in any case, other things being equal, they should inevitably last longer on an electric vehicle where the stresses are more evenly applied than in one where a gear-box and clutch are used.

Gear Drives.—In cases where a motor is geared direct to each driving wheel a good deal of trouble has arisen due to

the grease getting into the motors, but the actual gearing has given no trouble at all. Where the motors are mounted remote from the wheels, and the gear is through shafting the grease difficulty is eliminated, but the universal joints and other extra parts required give rise to complications which are not accompanied by any corresponding advantage, and this type of drive requires incomparably more attention than any other.

The author's direct experience of the single motor "Balanced" drive through gears in the driving wheels has been confined to two vehicles, one of which has done 23,000 miles and the other 18,000 miles, the former being a 1-ton and the latter a 10-ton machine. No trouble of any kind has occurred with either machine, and the wear on the gears has been quite negligible.

Steering Gear, Brakes, etc.—These follow standard petrol car practice in most cases, but some trouble has been experienced with brakes operated by steel cables instead of rods and having inadequate surface area. It is, however, unlikely that these defects will recur on modern vehicles.

This is the whole story of the mechanical troubles experienced on a fleet of 40 vehicles (19 belonging to Glasgow Electricity Department and 21 to Cleansing Department), comprising practically every make readily procurable in Great Britain. The very meagreness of the record is fair evidence of the fact that no one need fear the modern electric vehicle on this score.

Electrical Equipment.—*Motors.*—American motors on electric vehicles in the Glasgow Corporation Electricity Department have a perfect record of reliability, no failure of any kind having occurred throughout the 10 years during which they have been used. British-built motors have also an excellent record, the only failures being on early productions of the manufacturers. It should now be possible to guarantee complete immunity from trouble with the minimum of attention.

Controllers.—Drum-type controllers are almost always used on electric vehicles, and the arcing which occurs at the contacts makes it essential to have these examined and refaced regularly. Glasgow experience has been that one hour per vehicle per week is amply sufficient to keep the controllers in good order. The use of an auxiliary breaker working in conjunction with the foot brake is also of considerable service in reducing the duty on controller fingers. A special type of controller of the plate type is in use on many of the vehicles. This type would appear to have distinct advantages especially from a manufacturing point of view, but in actual experience it is much inferior to the drum type. One of the serious weaknesses of 2-motor drive lies in the extra complication of the controller. In such cases there has been several cases of trouble due to the circuit through one motor being left open so that the remaining motor was overloaded and consequently damaged. Control resistances have had to be renewed in some instances, the defects in all cases arising in elements of the cast-iron grid type. Well-constructed strip resistances are practically indestructible with normal use, and should last as long as any part of a vehicle. The general conclusion arrived at is that motors, controllers and wiring give even less trouble than the mechanical portions.

Accessories.—The only instruments provided on most British and American electric vehicles are odometers (mileage meters) and ampere-hour meters. The former instruments are, of course, fitted to almost all mechanically propelled vehicles, and are for the most part very reliable. Ampere-hour meters have proved very useful on the vehicles under consideration, but it must be admitted that they have frequently required skilled attention, and it is practically hopeless to expect more than one year's accurate service before a thorough overhaul becomes necessary. The author suggests that every vehicle should in addition be provided with an ammeter and voltmeter, with the aid of which an intelligent driver

could at once detect anything seriously amiss with his vehicle.

Batteries.—Except in this vitally important part the electric vehicle is actually or potentially superior to any other type, but the admitted weakness of the battery has so far prevented it from making much progress. The modern battery is, however, a great improvement on the type on which many engineers base their condemnations of electric vehicles as a whole. The following notes give the author's personal experience of various types of batteries maintained by men who had no real training in the work. The different types will be dealt with separately.

Lead Batteries of the Exide Ironclad Type.—Early experience with this type of battery as built in England was not encouraging, as, although the makers stood up to their guarantee of 2 years' life, many batteries failed within that period. The main causes of failure were (1) faulty construction of the positive plates. (2) Vehicle makers providing too small batteries for the duty the vehicles were called to do. (3) The very bad road surfaces on which the vehicles operated. The manufacturing weaknesses have of late practically disappeared, and no reasonably used battery has failed within its guaranteed period for a considerable time. The best results so far obtained has been a life of 31 months. During that period the vehicle covered 17,000 miles, and the total number of cycles of charge and discharge was 890. There seems to be every prospect of obtaining 3 years' satisfactory service from modern examples of this type of battery, but at present, costs should be calculated on the assumption that a battery must be scrapped after 2 years' use or, say, 600 complete cycles of charge and discharge.

Lead Batteries of the Flat Plate Type.—The author's experience of this type has been somewhat limited, and the batteries installed have not been in use sufficiently long to enable him to give any reasonably accurate estimate of the

probable life obtainable. It seems, however, to be certain that they will last sufficiently long to be serious competitors of any other type. It should be observed that this is almost the only type of battery used for electric vehicle work on the Continent. The great advantage of the flat-plate battery lies in its high output per unit of weight and volume. This is particularly the case with certain batteries of German manufacture.

The most favourable line of development of this type of battery would appear to be in manufacturing cheap thin plate cells with positive plates capable of giving about 1 year's service. The negative plates and containers would be removed every 2 years. In this way it should be possible to get very satisfactory economic results.

Battery Assembly.—The generally accepted practice of mounting several cells together in crates has not proved to be wholly satisfactory. The disadvantages of the system are (1) that the battery crates used by different makers have not been standardised. (2) Individual cells are rendered less accessible. (3) The cost of the crates is a very serious consideration. Glasgow experience has been to the effect that the best arrangement is to have two main battery boxes into which the individual cells are carefully packed by means of wooden separators, care being taken to get adequate ventilation. This makes it comparatively easy to withdraw any cell for examination or repair. A complete box is, of course, somewhat heavy, but it can easily be handled mechanically. The type of connection to the cell terminals is of great importance. Where these are burned no trouble arises if convenient tools are provided for connecting and disconnecting. The Chloride Company's equipment is very satisfactory. Bolted connections must be carefully tended to prevent them from becoming corroded. The system of the Philadelphia Storage Company of America where the positive connection is burned and the negative bolted is probably the best scheme which has come to the notice of the writer.

Alkaline Batteries.—Alkaline batteries, particularly those made by the Edison Company, are extremely sound mechanically, and the only attention required apart from supplying distilled water is that they should be kept clean. One or two instances of failure of individual cells have occurred within the guarantee period, but these were in all cases due to accumulations of dirt, which caused corrosion of the cell-containers. Proper covering of the cells removes all possibility of this trouble. A point which hardly seems to be sufficiently appreciated by users of alkaline batteries is that the charging must be carried out at a high rate, slow charges being practically useless. Another very important point in the maintenance of Edison batteries is to ensure that the electrolyte is changed regularly. This should be done about every 300 cycles of charge and discharge, or, say, once annually. The use of proper mechanical appliances for shaking and emptying the cells is essential if this is to be done economically. The best result obtained from an Edison battery so far has been a life of 8 years or 2,400 cycles. This battery is still in operation, and is still giving 80% of its rated discharge.

On the whole, the maintenance of batteries of all well-constructed types is by no means the ordeal that it is generally understood to be. The essential requirements are to keep the cells scrupulously clean, to use only pure distilled water for topping purpose, and to keep careful records of the voltage and specific gravity of all cells. These records should be kept so as to allow of any trouble being diagnosed and eliminated in its early stages. It should also be observed that while battery maintenance does not call for any great amount of skill or knowledge, the persons in charge of batteries should if possible be drawn from the maker's works, or they should receive some training with proper demonstrations from a highly experienced man. It is only by encouraging the man to take a thorough interest in the work that the best results can be obtained.

In the larger cities, at least, it would be far more satisfactory if all battery repair work were centralised and kept in the hands of thoroughly trained men. If this could be done and a proper system of providing spare batteries arranged, an electric vehicle owner would be able to operate his machines with the minimum of trouble and expense.

Tyres.—A very common claim on behalf of electric vehicles is that tyre wear is greatly reduced due to the even drive. In many instances, in the author's experience, very long mileages (up to 30,000 miles) have been obtained. It has been found, however, that far more satisfactory overall results are obtained by using thick and comparatively soft tyres which only last for about 15,000 miles, than harder tyres with longer life and reduced road resistance, the benefit to chassis and body more than compensating for the extra tyre and energy costs. It should be noted that these remarks apply to vehicles operating for the most part on very rough surfaces. In cases where the road surfaces are smooth hard tyres will probably be most satisfactory.

The Transport Work of an Electricity Supply Undertaking.

Practically the whole of the transport work of the Glasgow Corporation Electricity Department is done by means of electric battery vehicles, and a general description of vehicles used and the work on which they are engaged is given, in the hope that it may prove useful to other electricity supply authorities who are considering the use of similar machines.

The vehicles forming the fleet were with one exception purchased by W. W. Lackie, Esq., C.B.E., late Chief Engineer and Manager of the above department, who was one of the first municipal engineers to recognise the great value of such machines.

There are 19 vehicles in use made up as follows :—

2 Vans each of 1-ton capacity.

Plain platform lorries—1 1-ton, 1 1½-ton, 4 2-ton, 1 2½-ton, 1 3-ton.

Tipping Lorries—2 2-ton, 1 2½-ton, 1 3½-ton.

4 Ash Wagons with steel tipping bodies, 5-ton.

1 Tractor of 10-ton load capacity.

The vans are used in connection with the showroom services for delivering domestic electric utensils, such as radiators, cooking ranges, hot plates and irons. They are also used for transporting meters, and testing material for the Laboratory and Street Lighting Sections. In addition, a regular service is run by one van to deliver hot lunches from a central kitchen to different sections of the city where the departmental workmen are employed.

Lorries.—The lorries are utilised for delivering materials and tools used by workmen engaged in cable and sub-station extension work, and for removing earth after cable-laying operations. It should be noted that all cable-laying work is done by the department's permanent employees.

All the ash wagons were originally used for removing ashes from power stations, but some are now on ordinary cartage work.

The tractor is generally employed in delivering cable drums to the laying squads, but is also used for shifting transformers and other types of machinery within the limits of its capacity.

The vehicles with the exception of the 5-ton machines are very fully occupied throughout the year. They all operate within a limited radius (approximately 5 miles), and the average daily mileage is only about 20 to 35. The maximum mileage yet recorded for a single day is 50; this distance was done in the course of ordinary working, but, of course, such distances are very seldom called for in town transport work.

Conclusions to be drawn from Glasgow Experience.

Although the mixed nature of the Glasgow Corporation vehicles and the varied work on which they are engaged make it difficult to get exact comparisons between the different types of machines, general conclusions as to what can be done with electric vehicles are, however, readily deduced. The most important of these conclusions are :—

(I) At least 90% of the transport work of a municipal electricity supply undertaking can be done conveniently and efficiently by means of electric vehicles.

(II) All parts of most modern electric vehicles give excellent service even under very bad conditions, such as uneven road surfaces, very high average road resistance, hilly roads.

(III) There is practically no limit to the useful life of a well-designed and manufactured electric vehicle. After 100,000 miles' running, one vehicle is running quite as well as when it was new. The renewals necessary are quite easily carried out, and the wearing parts are of the simplest description.

(IV) There is practically no danger of a good electric vehicle breaking down on everyday service.

(V) The tool equipment necessary to maintain even a very large and mixed fleet of electric vehicles is of the simplest possible description.

(VI) An Edison battery lasts 8 years if properly used, while a good lead battery lasts at least 2½ years if its capacity is carefully chosen to suit the work it is put to.

These deductions are all commonplace and are simply corroborations of the claims of vehicle and battery builders.

It must be recorded here that the use of vehicles of different makes, which is justified in this instance because of the necessity for giving the different manufacturers an opportunity of doing

business in the district, is most undesirable. Although the mechanical repairs to any of the vehicles are negligibly small, the differences in such important points as tyres, cells, controller fingers, motor brushes and chains very materially increase maintenance charges. It is absolutely certain that a uniform fleet of good electric vehicles on work similar to that described above could be done with the minimum of difficulty, and there would be no occasion to keep more than one man with special training. The wider experience gained from the different types of vehicles is also far less valuable in the long run than the exact knowledge of one type, and the better commercial results which inevitably accompany this.

CHAPTER VI

WORKING COSTS OF ELECTRIC BATTERY VEHICLES

THE range of load capacities over which the battery vehicle of normal 4-wheel design has proved suitable is from ½ ton to 5 tons. The ½-ton and 1-ton sizes have not made much headway, chiefly because of the very cheap and efficient petrol vehicles which are available for loads of this order. Five-ton vehicles are in fairly common use, but beyond this capacity the steam wagon seems to be the most satisfactory type of machine. Electric vehicle manufacturers are endeavouring to meet the competition in the light and heavy types by special designs. For light loads 3-wheeled cars are being used, and 6-wheelers are being developed for heavy loads of from 6 to 10 tons. In this chapter proved costs of running 4-wheel cars of ½, 1, 1½, 2, 3½, and 5 tons capacity will be given, but only estimates of the costs for 3- and 6-wheel machines can be given.

The subdivision of costs is made in the usual way, the sections being—

(1) Standing Charges:—Interest and Depreciation, Licence, Insurance, Garage Charges, and Wages.

(2) Running Costs made up of Charges for Electrical Energy:—Battery Renewals, Tyres, Body, and General Repairs.

The costs of vehicles, batteries, and tyres are present-day (February 1924) prices obtained from makers whose products have proved to be capable of giving satisfactory service over the length of time and distance stated.

The maximum annual mileage considered is 10,000 miles. This distance gives a daily mileage of 10,000/300 = 33·⅓ miles for 300 working days per year, and as this distance is well above the average for petrol cars on city delivery work, it is considered to be sufficient for practical requirements. It can be extended under most conditions to 40 miles per day per battery charge, but if longer distances have to be run it is necessary to make provision for exchanging batteries.

A life of 15 years or 150,000 miles has been taken as the base of the calculations of the depreciation figures. This life can very easily be attained with electric vehicles even when running on very bad road surfaces, and many machines with over 20 years' service are still running well in both London and New York.

The items which have been considered in making up the estimates for the maintenance of the vehicles are :—

(1) Regular inspection and renewal of wearing parts of the Controllers and Motors.

(2) Renewals of Chains and Sprockets or corresponding reduction gearing.

(3) Renewal of Lorry Bottoms.

(4) Repainting.

(5) An overhaul of the whole vehicle every two years.

This overhaul need not occupy more than one week, and can easily be done by a mechanic and helper. It must be emphasised here that such an overhaul is a very simple matter with an electric vehicle, as there is practically no highly accurate work involved. The allowance for battery renewals is ample to cover all maintenance work on the batteries themselves.

The first table of costs gives the base for the calculations (Table of First Costs and Running Costs of Electric Battery Vehicles).

Dealing with the special case of a 2-ton lorry, it is seen

from the table that the annual costs arranged in order of magnitude are :—

	£.	%.
1. Driver's Wages	150	29·0
2. Battery Renewals . . .	120	23·3
3. Depreciation and Interest .	98	19·0
4. Electrical Energy . . .	51	9·9
5. Licence	25	4·8
6. Garage	22	4·2
7. Maintenance	19	3·7
8. Tyres	16	3·5
9. Insurance	14	2·6
	£515	100·0

The percentage scale shows clearly the relative importance of the different items, and where the greatest possibilities of effecting improvement arise. The first item is independent to a great extent of the class of vehicle driven, and while it is often claimed that a lower grade of driver can be used for electric vehicles than for other mechanically propelled machines, the author is firmly convinced that the employment of low-grade drivers is not economical. Battery renewals rank next to the driver's wages, and this item is probably the one which is chiefly responsible for the slow development of electric vehicle work in Britain. The first cost of batteries is very high primarily because of the limited demand for them, and as the cost of the raw materials is fairly low, there should be good prospects of substantial reductions in the price of the finished article if a sufficient demand is forthcoming. There is, unfortunately, no immediate prospect of drastic reductions in the first costs of batteries, but it is almost certain that it will soon be possible to reckon on a 3 years' life for batteries at the prices quoted in the table. Under these conditions it will be possible to reduce item (2) by $33\frac{1}{3}$%. The third item can only be reduced by increased demand for

electric vehicles. The fourth item (cost of electrical energy) cannot readily be reduced except by reduction in the price of the electricity itself as only small improvements in battery and vehicle efficiencies are possible with the conventional designs. The basic cost of electrical energy taken in this case is $1\frac{1}{2}d.$ per kw.h., but it should be quite possible to reduce this to half when the supply is taken from even reasonably efficient power stations. It should be noted, however, that a reduction of 50% in the price of current only means a reduction of about 5% in the total running cost of the vehicle. The remaining items are relatively small and only trifling reductions in running costs can be made through them.

The 2-ton electric vehicle has proved to be the most serviceable in the author's experience for general cartage work, and this and the larger sizes will be found to be quite capable of competing economically with any other type for this class of work. Care must, however, be taken to ensure that fair comparisons are always made, and the common error of taking figures obtained from petrol and steam wagons working on long non-stop runs as representative of City conditions must especially be avoided. The Curves of Costs per Useful Ton-mile show the tremendous disadvantages of the light electric vehicle as regards running costs, and their use can only be justified under very special circumstances, *e.g.*, for the transport of goods which are readily spoilt by oil fumes. To reduce the cost of transport of light loads, say up to $\frac{1}{2}$ ton, 3-wheeled electric vehicles have been tried. The first cost and battery renewal costs are greatly reduced in this way, and it is claimed by one British manufacturer that the running cost of his machine need not exceed $\frac{1}{2}d.$ per mile. The Tribelhorn tri-cars used by the Swiss federal post are reputed to show a saving of over 40% as compared with similar petrol vehicles. For very heavy loads, the General Vehicle Company has introduced 6-wheeled models which are reputed to be extremely

economical, the energy consumption being only 70 watt-hours per gross ton-mile. These vehicles seem to present

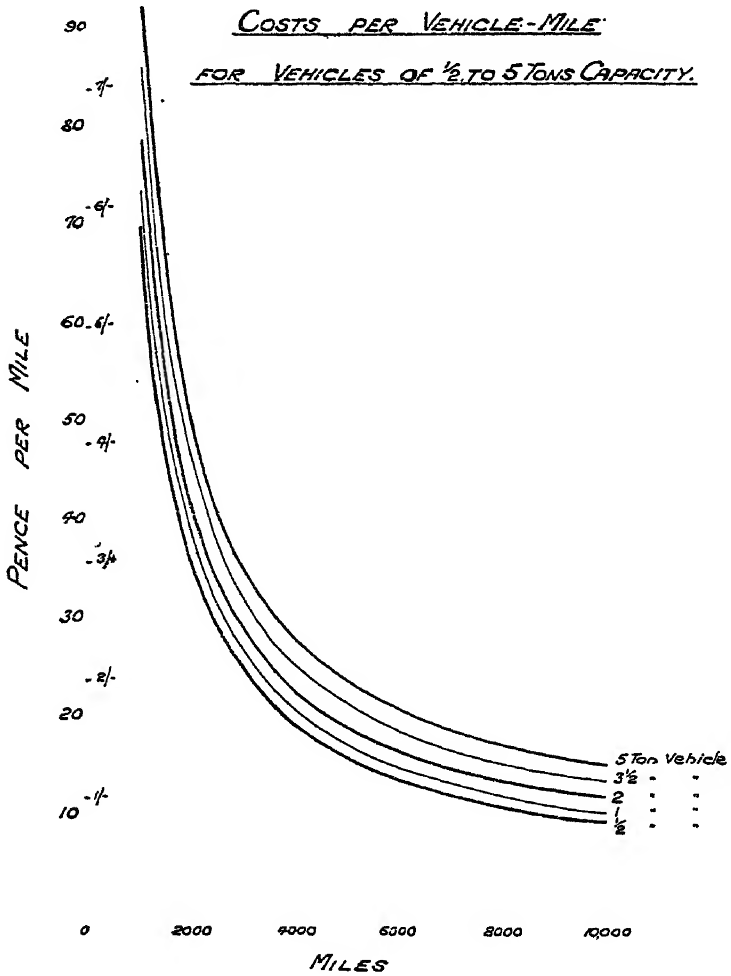

FIG. 39.—Costs per Vehicle-Mile for Vehicles of ½ to 5 Tons Capacity.

very great advantages for short-distance transport of heavy loads.

Coming to the vital question of relative costs of transport by Petrol, Horse, Steam, and Electric Vehicles, it must first

be noted that practically no reliable data as to actual costs of working machines of different types on the same class of work

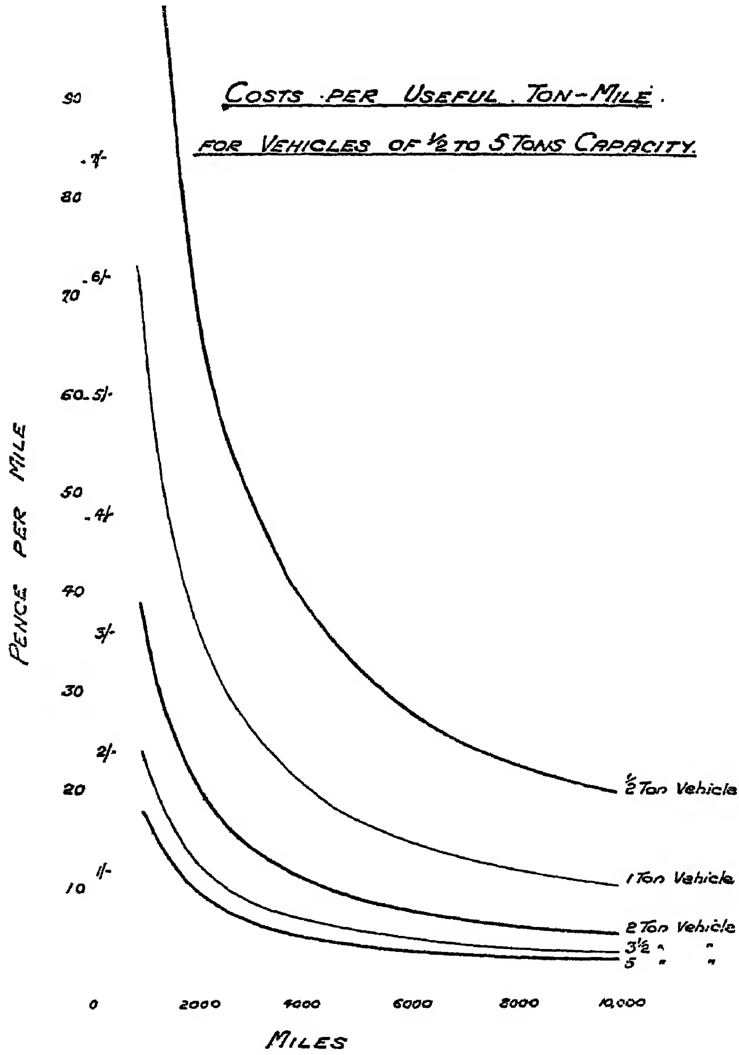

FIG. 40.—Costs per Useful Ton-Mile for Vehicles of ½ to 5 Tons Capacity.

arę available. In the present instance, comparisons of the author's figures for electric vehicles are calculated from figures

stated by C. G. Conradi as representing good results obtainable with Steam and Petrol Vehicles. The costs are given per vehicle-mile, but the useful ton-mile costs are readily deduced therefrom.

Capacity of Vehicle. Tons.	Cost in Pence per Vehicle-mile.		
	Electric.	Petrol.	Steam.
½	10	8·9	—
1	10·9	9·2	—
2	12·4	12·8	—
3½	14·3	15·2	—
5	15·8	17·1	18·8

All these figures are based on the assumption that the annual mileage run is 10,000 miles per vehicle. The deduction to be made from the above table is that the electric vehicle is cheapest to run if the load capacity is from 2 to 5 tons, while the petrol vehicle is the cheapest for loads below 2 tons. Statistics as to operating costs for horse-drawn transport are still more difficult to obtain, and because of this a comparison has been made between the running costs of electric vehicles as stated above with the hire charges for horses and carts prevailing in Glasgow. The standard method of charging is to give a price for the hire of horse and cart with driver for a day of 8 hours. The present figures are 17*s.* for an unsprung cart, and 18*s.* for a spring van. The daily costs for operating electric vehicles are :—½ ton 28*s.*, 1 ton 30*s.*, 2 tons 34*s.*, 3½ tons 39*s.*, 5 tons 44*s.* These sizes of vehicles must therefore be respectively capable of doing the work of 1·55, 1·67, 1·89, 2·17 and 2·45 horses and carts, if they are to justify themselves economically. That electric vehicles are capable of doing the required amount of work is beyond question, and where conditions permit of them being fully employed they are preferable in every way to horse-drawn vehicles.

Table III.

First Costs and Running Costs of Electric Battery Vehicles.

Load Capacity (Tons).	1/2.	1.	2.	3½.	5.
Chassis	£406	£435	£501	£619	£706
Battery	192	220	240	260	300
Plain Lorry Body	70	74	77	80	82
Tyres	14	15	24	31	44
Total Cost	£682	£744	£842	£990	£1132

Annual Standing Charges.

1. Driver's Wages	£150	£150	£150	£150	£150
2. Depreciation, 6⅝%	45	50	56	66	75
3. Interest on Capital, 5%	34	37	42	50	57
4. Licence	21	21	25	28	30
5. Garage Charges	18	20	22	24	26
6. Insurance	11	12	14	16	18
(*a*) Total (1) to (6)	£279	£290	£309	£334	£356

Running Costs (based on 10,000 miles per annum).

7. Battery Renewals	£96	£110	£120	£130	£150
8. Electrical Energy	19	29	51	80	102
9. Tyres	9	10	16	21	29
10. Maintenance	16	17	19	21	23
(*b*) Total (7) to (10)	£140	£166	£206	£252	£304

(*a*) + (*b*)	£419	£456	£515	£586	£660
Cost per Vehicle-mile (pence)	10	10·9	12·4	14·3	15·8
Cost per Useful Ton-mile (pence)	20	10·90	6·20	4·08	3·16

CHAPTER VII

ELECTRIC VEHICLE TESTS—SUPPLEMENT TO "ELECTRIC VEHICLE TESTS"

Electric Vehicle Tests.

THE reliability of a well-designed and constructed electric vehicle is so satisfactory that there is comparatively little need for any testing at all. It is, however, of great interest and value to have accurate test results showing exactly what any particular vehicle can really do. The user is then in a position to make proper comparisons between different makes and types of electric vehicles, and is in a much better position to estimate his ability to compete with horse, steam and petrol transport. The notes which follow are based directly on the author's personal experience, and the tests described are as thorough as the conditions of working allow. Manufacturers and designers would, of course, find it necessary to make more elaborate tests and analyses of losses, but it is hoped that the simpler methods adopted here will be of some benefit to the user of electric vehicles.

The procedure followed by the author is to follow closely the behaviour of each vehicle in ordinary working by keeping records of the ampere-hours and watt-hours per mile run, and to rectify any simple trouble, such as brake binding, which is causing an increase of the energy consumption. A complete overhaul is carried out on each vehicle every two years, and after this overhaul the vehicle is thoroughly tested to ensure that it is ready for its regular work.

The tests after overhaul are as follows :—

(1) Test for freedom and soundness of Transmission System.

(2) Road Test to determine whether or not the power and energy consumptions are normal.

The first test is made by jacking up the driving wheels of the machine, and applying a low voltage to the motors with the controller on the " full on " position. The applied voltage is varied from a very low value up to such a value as will drive the wheels at a speed equivalent to 20 miles per hour on the road. The readings taken are Voltage, Current to each Motor, Speed of each Driving Wheel. This test gives a very rough approximation to the absolute transmission losses, and a clear indication as to whether they are better or worse than a previously established standard. The highest equivalent speed of 20 miles per hour is chosen as being about the maximum likely to be reached in practice. This test can be greatly improved by separately exciting the field windings of the driving motors, and if this is done the transmission and motor losses can be more accurately determined. This refinement was, however, not adopted by the author owing to the necessity for special supervision which it entailed.

When it has been established that the transmission system is in good order, the vehicle is fully loaded and proceeds on its road test. On this test a special observer accompanies the driver to make the necessary observations. The readings taken are Battery Voltage, Total Current from Battery, Current to each Motor, Ampere-Hours, Mileage. Readings on the indicating instruments are taken at regular space intervals, and in addition a continuous record of the total current taken from the battery is taken by means of a specially suspended recording ammeter. The chief difficulty in making these tests lies in the severe vibration to which the instruments are subjected when the vehicle is running on bad road surfaces. To get over this trouble, the ammeters and voltmeters are mounted on a board which the observer supports on his knees.

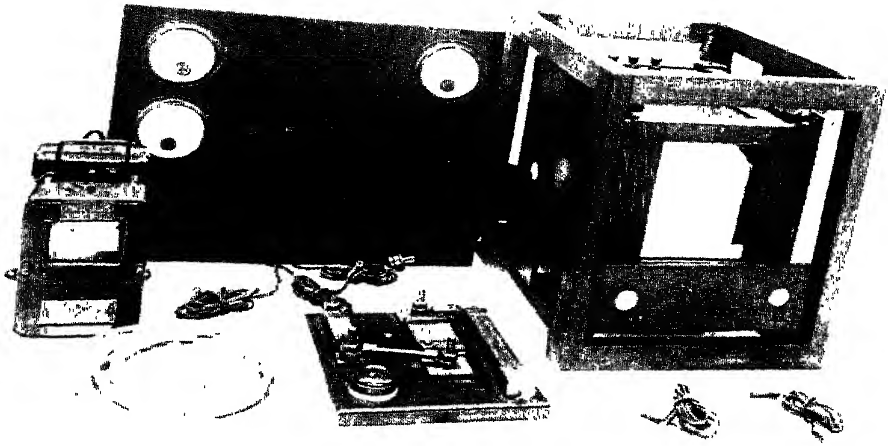

FIG. 41.—Vehicle Test Instruments.

[*To face page 78.*

The same board is used for carrying the record sheets, and this system has been found to be very satisfactory, and convenient in practice. The recording ammeter used is a standard portable Everett and Edgcumbe instrument mounted in a frame with ordinary tennis balls at the corners for damping out vibrations. Very satisfactory results have been obtained with this instrument and suspension system. The speed of the vehicle is got by calculation from stop-watch readings of the time taken to traverse known distances. This is the most unsatisfactory of all the measurements, and it would be a great improvement if a continuous record of the speed could be obtained. The complete report on figures obtained from one road test are given to illustrate more clearly the method of procedure.

Road Test on Electric Vehicle No. 12.

Type of Vehicle.—Light van.

Load Capacity.—One ton.

Transmission System.—Single motor in back axle driving through gears in driving wheels.

Type of Battery.—Edison, 60G9 cells. Capacity at 5-hour rate, 225 ampere-hours. Normal full-load current, 45 amperes.

Test Route.—Ferry Road Yoker to Shettleston Tramway Depot and back to starting point.

Weather Conditions during Test.—Wet. Calm.

Observer.—D. Hogg.

Driver.—W. McNab.

Date of Test.—12th October, 1923.

Observed Figures.

Weights.—Total weight of vehicle and load (including driver and observer), 3·495 tons. Weight of vehicle, 2·350 tons. Weight of load, 1·140 tons.

Distance Run.—16·0 miles (measured from map); 15·9 miles (by odometer on vehicle).

Total Running Time.—94 minutes 30 seconds = 1·57 hours.

Ampere-hours used.—80·96 (by standard ampere-hour meter); 79 (by integration from chart).

Average Voltage at Battery Terminals.—68·6 volts.

Figures Calculated from above Observations.

Gross Ton-miles (3·495 × 16) = 56.

Ampere-hours per Gross Ton-mile (80·96/56) = 1·44.

Watt-hours per Gross Ton-mile (1·44 × 68·6) = 99.

Ampere-hours per mile (80·96/16) = 5·05.
Watt-hours per mile (5·05 × 68·6) = 346.
Average Speed (16/1·57) = 10·2 miles per hour.
Average Current (80·96/1·57) = 51·5 amperes.
Average Power (51·5 × 68·6) = 3·53 kilowatts.

FIGURES ABSTRACTED FROM READINGS OF INDICATING INSTRUMENTS OR FROM RECORDING AMMETER CHART.

Maximum momentary Current (starting).—200 amperes.
Maximum momentary Power (starting).—10·8 kilowatts.
Maximum sustained Current (2 minutes' duration).—92 amperes.
Maximum sustained Power (2 minutes' duration).—4·6 kilowatts.

Deductions.—The average load on the battery is 51·5/45 = 1·14 times its normal full load. The maximum instantaneous load is 200/45 = 4·45 times full load, and the maximum sustained load 92/45 = 2·04 times full load.

The average input to the motor is 3·53 kilowatts or 4·75 horse-power. The maximum momentary power input is 10·8 kilowatts or 14·5 horse-power and the maximum sustained load 4·6 kilowatts or 6·17 horse-power. The vehicle makers do not state the rated power of the motor, so that the percentage overloads cannot be calculated.

The mileage per charge obtained with this vehicle carrying full load on a route of the same nature as to surface and gradient as the test route would be (16 × 225/81) = 45 miles, this figure being based on the assumption that the battery will give its full rated output of 225 ampere-hours when working at 1·14 times its normal load. (The actual mileage run by this machine on each battery charge in its ordinary work is about 31 miles, but 40 miles is frequently obtained without attempting to run the battery to exhaustion.)

The energy required for running the loaded vehicle is 346/0·5 = 692 watt-hours per mile, assuming a battery watt-hour efficiency of 50%. The cost per mile at 1·5 pence per kw.h. (the present cost of energy to electric vehicle users in Glasgow) is 0·692 × 1·5 = 1·035 *pence per vehicle-mile.* The energy cost per gross ton-mile is 0·3 of a penny, and per ton-mile of load 0·91 of a penny.

The combined road and air resistance may be deduced approximately from the energy consumption thus—Taking 80% for the overall efficiency of motor and transmission gear, the total energy expended in overcoming road and air resistance and in accelerating the vehicle is $0{\cdot}8 \times 99 = 79$ watt-hours per gross ton-mile, so that the total resisting force per ton is 39·6 *pounds.*

The ordinary running of the vehicle is done under conditions similar to those existing on the test route. The average speed obtained on a route free from traffic by the same vehicle was 12 miles per hour.

Summaries of tests made on other vehicles are tabulated below to indicate the variations in results which have been obtained.

The test results show clearly the great variations in load which the motors and batteries have to deal with. They show the necessity for designing motors which have high overload efficiency with low applied voltage.

The necessity for properly chosen battery capacity is very evident. In the present instance the battery capacity provided by some vehicle makers is wholly inadequate, and it does not seem to have been realised that an over-worked battery, especially if of the lead type, has a very short working life. In addition, the performance of the vehicle is very much less satisfactory than would be the case with a larger battery.

ROAD TEST ON ELECTRIC VEHICLE No. 051EE.

Type of Vehicle.—Platform lorry.
Load Capacity.—3·5 tons.
Transmission System.—Two motor. Gear motor.
Type of Battery.—A.F.A., 80 KY cells. Capacity at 5-hour rate, 250 ampere-hours. Normal full-load current, 50 amperes.
Test Route.—Waterloo Street—Old Kilpatrick—Port Dundas via Dalmuir and Maryhill.
Weather Conditions during Test.—Dry. Calm.
Observer.—D. Hogg.
Driver.—W. MacIntyre.
Date of Test.—28th March, 1923.

Table IV.

Summary of Results of Road Tests on Battery Vehicles.

No.	Particulars Regarding Vehicle.				Battery.		Test Results.				
	Type.	Transmission System.	Unladen Weight (Tons).	Load during Test (Tons).	No. of Cells in Series.	Capacity Amp. Hours.	Average Power to Motors (K.w.).	Average Current (Amps.).	Average Speed Miles per hour.	Watt-hours per Gross Ton-Mile.	Road Conditions and Remarks.
1	½-Ton Lorry.	1 M.C.D.	2·428	0·64	44	168	3·95	46	11·6	109	Normal.
2	1-Ton Van.	1 M.C.D.	2·025	1·14	60	225	2·49	35	8·3	98	do.
3	1-Ton Van.	1 M.G.D.	2·35	1·14	60	225	3·53	52	10·2	99	
4	1½-Ton Lorry.	1 M.C.D.	3·00	1·625	42	240	5·28	66	9·4	122	Soft.
5	1½-Ton Van.	1 M.G.D.	4·3	0	44	312	7·45	94	12·5	140	
	do.	do.	4·3	1·25	44	312	7·00	86	12·5	101	
6	2-Ton Lorry.	2 M.G.D.	4·1	2·05	60	300	6·6	96	9·2	116	
7	3-Ton Lorry.	2 M.C.D.	4·98	0	40	258	5·7	76	8·1	138	
8	3½-Ton Lorry.	2 M.G.D.	4·075	3·5	80	250	5·9	35	10	77	
9	5-Ton Lorry.	1 M.C.D.	5·013	2·625	60	240	6·19	91	8·1	100	
10	5-Ton Lorry.	4 M.G.D.	5·87	5·155	42	323	13·5	188	7·1	173	Soft Snow on Ground.
11	10-Ton Tracter.	1 M.G.D.	3·262	5	42	450	10·1	131	4·5	164	Plain Bearing Trailer.

1 M.C.D. = 1 Motor, Chain Drive.
2 M.C.D. = 2 Motors, do.

1 M.G.D. = 1 Motor, Gear Drive.
4 M.G.D. = 4 Motors, do.

40, 42, 44, 80 Cell Batteries—Lead.
60 do —Alkaline.

OBSERVED FIGURES.

Weights.—Total weight of vehicle and load (including driver and observer), 7·57 tons. Weight of vehicle, 3·96 tons. Weight of load, 3·61 tons.
Distance Run.—20·4 miles (measured from map). No odometer fitted to vehicle.
Total Running Time.—122 minutes = 2·03 hours.
Ampere-hours used.—75 (by standard ampere-hour meter). No ampere-hour meter fitted to vehicle.
Average Voltage at Battery Terminals.—160·4 volts.

FIGURES CALCULATED FROM ABOVE OBSERVATIONS.

Gross Ton-miles (7·57 × 20·4) = 154.
Ampere-hours per Gross Ton-mile (75/154) = 0·486.
Watt-hours per Gross Ton-mile (0·486 × 160·4) = 78·0.
Ampere-hours per mile (75/20·4) = 3·67.
Watt-hours per mile (12030/20·4) = 589.
Average Speed (20·4/2·03) = 10·03 miles per hour.
Average Current (75/2·03) = 36·9 amperes.
Average Power (36·9 × 160·4) = 5·95 kilowatts.

FIGURES ABSTRACTED FROM READINGS OF INDICATING INSTRUMENTS OR FROM RECORDING AMMETER CHART.

Maximum momentary Current (starting).—200 amperes.
Maximum momentary Power (starting).—32 kilowatts.
Maximum sustained Current (2 minutes' duration).—90 amperes.
Maximum sustained Power (2 minutes' duration).—14.44 kilowatts.

Supplement to "Electric Vehicle Tests."

By far the most thorough series of electric vehicle road tests which has ever been carried out in Europe is that which was completed in September and October 1923 in Paris, under the auspices of the Union des Syndicats de l'Électricité. The thoroughness with which these tests were conducted and the methods adopted to ensure absolute accuracy in all measurements form a sound model for any succeeding tests, and for this reason an outline of principal features is given here.

The vehicles to be tested were divided into separate categories according to their rated loads, thus :—

Class 1.	Useful Loads		0 to 500	kilograms	(½ ton)
,, 2.	,,	,,	501 ,, 1500	,,	(1½ tons)
,, 3.	,,	,,	1501 ,, 3000	,,	(3 ,,)
,, 4.	,,	,,	3001 ,, 5000	,,	(5 ,,)
,, 5.	,,	,,	5001 and above	,,	

These classes could be further subdivided according to the type of battery used, and the rated distance run per battery charge.

The object of the tests was to determine :—

1. The consumption of electrical energy per useful ton-kilo-metres.

2. The consumption of electrical energy per total ton-kilo-metres.

The garaging, charging of batteries, and repairs, was under strict official supervision during the whole of the test period.

The duration of the test was 10 days, and the daily distances to be traversed by the different classes were :—

Class	1.	80	kilometres.
,,	2.	70	,,
,,	3.	60	,,
,,	4.	50	,,
,,	5.	50	,,

Each vehicle was accompanied by an official whose duty it was to keep an exact note of all the necessary instrument readings, and of all incidents of importance.

The test loads were all accurately weighed and certified. All energy supplied to each vehicle was accurately measured, the energy lost in regulating resistances being charged against the vehicle just as though it had been supplied to the battery. This method of measurement gives an actual record of what energy the user of an electric vehicle must pay for.

The energy output of each battery was accurately measured by means of a specially designed watt-hour meter of the mercury type. The registration of this meter gave the useful energy plus the energy lost in resistances, wiring motors, gearing, etc.

Indicating ammeters and voltmeters were also mounted on the vehicles.

All instruments used during the tests were checked and certified both before and after use by the Laboratoire Centrale de l'Électricité. The routes were chosen to be representative of the hardest work likely to be met with in Paris, and exact profiles of all were taken. Inspectors were stationed at specified points to check the observations of the officials travelling with the vehicles.

The atmospheric conditions and the state of the roads was carefully recorded every morning and evening throughout the test period.

The vehicles tested were all of French manufacture, and the best figure of energy consumption obtained was about 103 watt-hours per gross ton-mile. As this figure is based on energy supplied to the battery, it shows that the efficiency of the motor and transmission gear of the vehicle giving it, must be very high indeed. The performances of most of the vehicles entered were not in any way noteworthy, and it is very regrettable that no entries from countries other than France were allowed.

CHAPTER VIII

ELECTRIC VEHICLE PRACTICE OUTSIDE GREAT BRITAIN

America is far ahead of any other country in the world in the construction and use of electric vehicles. The types of vehicles in use in America do not differ materially from British machines, in fact it is pretty obvious that almost every British-made vehicle is developed from an American design. The reason for this is that the electric vehicle industry was absolutely dead in Britain for about 20 years, and when the exigencies of war made it necessary to revive the industry builders very naturally took every possible lesson from American experience. The total number of battery vehicles in use in the United States of America is stated to be about 15,000, compared with about 1,500 in Great Britain. The populations are in the ratio of about 5 to 1, so that it may be said that the battery vehicle is used in America to twice the extent that it is used in Great Britain. In America, battery vehicles are used principally as delivery wagons, whereas they have been used most widely in Britain on municipal cleansing services. The enormous fleets of electric vehicles used by private transport firms in America, presumably because they form the most efficient means of carrying on their work, is probably the best augury for the future of the type. This is specially remarkable in view of the extreme cheapness of petrol motors and petrol in the United States. The great disparity between the costs of petrol and electric vehicles in the United States is seen from the fact that in 1920 a good 2-ton electric vehicle chassis cost eight times as much as a Ford chassis, the battery alone costing three times as much as the Ford. Petrol costs about

one-third as much in U.S.A. as here, and electricity costs about the same in both countries. These figures show that battery vehicles must have some extraordinarily good features in order to survive at all in face of such formidable competition. The author is of the opinion that the superior position of the electric vehicle in the States is due very largely to better organisation on the part of the American battery makers and electricity supply companies. The superiority in battery manufacture is readily explained by the vastly greater market for accumulators of all kinds. Electricity supply companies are interested in the sale of electric vehicles mainly because of their possibilities as a means of securing night load for the power stations. The objective of the American battery vehicle and electricity supply companies is to take over the whole of the city transport work which is at present done by horses, and also to replace petrol vehicles for short-distance transport.

The measures which are being taken to secure business are of a very practical nature. Each large supply company operates battery vehicles on its own transport work wherever possible, and, in addition, provides vehicles for demonstration purposes to interested parties. Special electric vehicle departments are established to provide clients with the most accurate and up-to-date information, and in one case at least a supply company has established a permanent showroom for vehicles. A few extracts from propaganda literature of the New York Edison Co. will serve to illustrate what is being done in this direction.

The Automobile Bureau of the above company bases its recommendations of the electric truck on its ease of operation and maintenance, low running costs and depreciation and great reliability. They illustrate the uses to which trucks are put by means of photographs of vehicles in the service of private companies wholly outwith the electrical industry. The largest fleet is that of the American Railway Express Co. with 1,347 vehicles, but it is interesting to note that the Consolidated

Gas Co. has 52 electrics. An illustration of a heavy electric vehicle on oil deliveries is also noteworthy. The total number of electric vehicles operating in New York City is given as 5,000, these being owned by 500 firms. In support of the claim for low depreciation a table is given showing the ages of vehicles in operation in New York Metropolitan District; 1,580 are over 10 years old, and 33 are 19 years old or more. Several extracts from statements by large users of electric trucks are given; these are mostly of a general nature, but when coupled with the numbers of vehicles used by the writers they show quite clearly that a good deal of headway has been made with this means of transport. The most important statement is that of the Vice-President of the American Railway Express Co. Here the upkeep of electric vehicles is given as 50% of that of other types. This figure is based on many years' experience, and is supported by the fact that 83% of recent purchases of trucks for this company have been for electrics.

The records of the same company show that in January 1923, a month in which the snowfall in the operating radius was 21·9 inches, 272 trouble calls were received from 207 petrol trucks, whereas only 113 trouble calls were got from 268 electrics.

The available evidence shows that, although in comparison with petrol vehicle development that of electric vehicles is trifling, yet American engineers are to be congratulated on having made a very good show against the more popular type.

The foregoing notes refer exclusively to commercial vehicles, but America has also developed the electric passenger vehicle, whereas it is practically unknown in Britain.

European Countries.—It is generally considered that electric vehicles have been developed to a very noteworthy extent in Germany, but, unfortunately, no connected accounts of the work done are available. The *Reichsanzeiger* of November 7th, 1921, gave a census of German Motor Vehicles

in which it was stated that there were 1,694 electric vehicles in Germany at that time. The relative proportions in which electric vehicles were used for different classes of transport work were—passenger cars 1·25%, heavy lorries 2·9%, and tractors 35%. These figures do not indicate any outstanding progress in Germany. The examples of German vehicles examined by the author in this country were not at all original in design, and their mechanical construction was very far from being up to the standard of good class British vehicles.

A very interesting and ingenious type of vehicle which has recently found favour in Germany consists of a front carriage or tractor with front wheel drive. The whole of the front part is mounted on a turn-table, and the steering can be done from the driver's seat in the ordinary way, or from road level by a man walking alongside the vehicle. In addition, such vehicles are made so as to give an extremely low loading line, and the type of body used can readily be changed. The advantages of these arrangements for such purposes as street cleansing are very obvious. Such vehicles are used for street sweeping and watering as well as for ordinary transport work. In Germany, lead batteries only are used in electric vehicles, and the usual practice is to have 40 cells. In heavy vehicles it is not uncommon to use double the number of cells. In such cases a very much greater amount of energy is stored per charge than is customary with British or American vehicles, and very great distances can be covered on one battery charge.

A German 3½-ton electric vehicle which was tested by the author had a 250 ampere-hour battery of 80 cells. This vehicle easily did 70 miles per charge on full load. It was also exceptionally speedy and efficient. A complete set of test figures for this vehicle is given on pages 78–80.

The batteries inspected by the author have had exceptionally thin plates, and the energy stored per unit of weight and volume was much higher than is usual in British or

American batteries. The cells were of the unsealed type, and the intention was evidently to replate them when required. On the whole, the construction of the cells was extremely good and compared very favourably with that of the products of any other country.

The Electric Vehicle in Switzerland.

Since Switzerland is further developed in the use of electricity than any other country in Europe, and is at least equal in this respect to the United States, one would expect the electric vehicle to be well developed there. In reality there is only one firm building such vehicles in Switzerland, and practically the whole of the development seems to be due to one man. The individual in question—Herr Tribelhorn, of Altstetten Zürich—has, however, done his work well, with the result that his firm has supplied over 600 vehicles in Switzerland. When the small size and population of the country are considered, this total is found to compare very favourably with the numbers in use anywhere else in Europe.

The Tribelhorn vehicles are of very interesting design. For very light vans a 3-wheeled chassis is used (Fig. 42). This machine has its drive on the rear wheels and the front wheel is used for steering alone. The controller is mounted on the end of the steering tiller and is extremely compact, as well as convenient for handling. The heavier Tribelhorn cars are provided with either gear or chain transmission, and differ very slightly from the products of other countries. Two-speed gears are used on vehicles which have to ascend gradients of over 15%. In addition to being used in the ordinary transport services, electric vehicles are extensively used by the Swiss Government for postal delivery work.

The development of batteries has, unfortunately, not kept pace with that of vehicles, and the only examples seen by the author were of the flat-plate type and were poorly constructed.

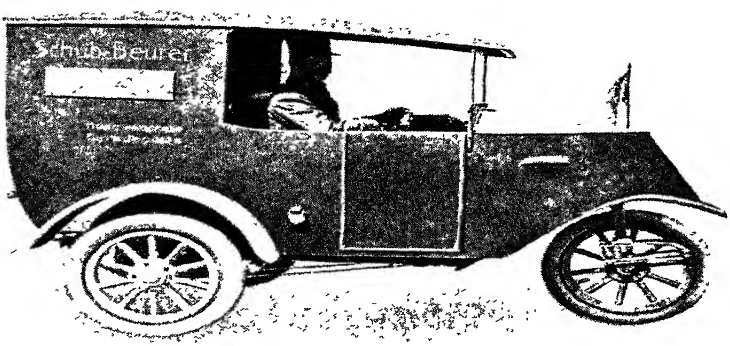

FIG. 42.—Tribelhorn 3-Wheel Vehicle.

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Electric Vehicles in France.

A good deal of pioneer work on battery traction was done in France while the petrol vehicle was still in the very elementary stages of its development. The work was, however, soon dropped, and at present France is far behind the other countries mentioned in battery vehicle work. The few vehicles in use are to be found in Paris and Nancy, and these have no features of special interest, the commonest type being light 3-wheeled delivery vans.

Within the last year or two interest in electric vehicles has revived to some extent, the reasons for the revival being the obvious value to the country in war time and a desire to utilise the plant in electric power stations to greater advantage. A very interesting article in the *Revue Générale de l'Électricité* for April 14th, 1923, shows the backward state of France relative to other countries so far as the number of electric vehicles used is concerned. The writer of the article, A. Canac, states that the types of vehicles which are mostly used outwith France are quite unsuitable for French working conditions, owing to the short mileage and low speed attainable with them. In order to exemplify what class of vehicle is wanted in France, he outlines the construction and performance of a 5-ton lorry built by the Société Anonyme des Anciens Établissements Laporte et Fils et Cie à Toulouse. This machine is of the 2-motor type, and the control system utilises resistances as well as series-parallel connections of both motors and battery sections. The battery consists of 80 cells of 250 ampere-hour capacity, and the normal distance traversed per charge on full load is given as 43 to 50 miles (70 to 80 kilometres). A 2-speed gear is provided to enable the vehicle to climb any hill without overheating the motors or putting an undue load on the battery. The energy consumption is from 0·6 to 1 kw.h. per vehicle-mile or from 0·12 to 0·2 kw.h. per useful ton-mile.

France has recently shown a much deeper interest in electric vehicles than formerly, but it is unfortunately doubtful whether this interest arises from conviction that the battery vehicle is a sound commercial proposition or whether it is simply its value as a substitute for the petrol vehicle in case of shortage of petrol which arouses it. The fact remains, however, that National Trials were conducted in September 1923 with a view to establish definitely the present position of the electric battery vehicle. Eighteen vehicles were entered, and the designs seemed to show that the manufacturers were totally ignorant of American and British practice, as many features, such as clutches and gear-boxes, had been introduced which experience had shown to be unnecessary and which are sources of weakness. The only vehicle which showed originality and appreciation of the real requirements was the Kriéger. This machine has neither front nor back axle, and the chassis is very light. The unsprung weight is reduced to a minimum. The Kriéger vehicles are reported to have performed very well on the official tests, which were very severe.

CONCLUSION

Prospect of Developments in Battery Vehicle Work.

THE class of electric vehicle which has proved most successful in Great Britain up to the present is the lorry of 1 ton to 5 tons load capacity. Machines of this type have been thoroughly developed, and have demonstrated their ability to operate conveniently and economically in city transport work and cleansing services. The onus of deciding whether they will or will not be used in greatly increased numbers lies principally with the electricity supply authorities. Electrical engineers should give the matter very close consideration with a view to determining whether their own goods transport cannot be done by electric vehicles. They should bear in mind that cranes can be easily fitted to such machines, that they provide easy and handy means of making pressure and fault location tests on cables, pumping out manholes, etc. They must also realise that electric vehicle builders are greatly handicapped in their endeavours to induce private firms to use electric vehicles by the fact that most electricity authorities have no vehicles of this type themselves. The objective to be aimed at is to obtain for electric vehicles practically all the city work at present done by horses, and when it is realised that a night load of about 1 kw. for 7 hours could be obtained for each horse displaced, the importance of the matter is evident. The total number of horses in Glasgow is 13,000, or about 12 horses to each thousand of the population, so that there is a potential demand for 13,000 kw. for transport work. To obtain this demand no expenditure for main generating plant or transmission cables is required. Practically the only expenditure

to be incurred is really for converting machinery for battery charging, the garage accommodation being already available, since the horses and carts at present utilise more space than would be required for electric vehicles of equivalent capacity.

Municipal cleansing departments have been the largest users of electric vehicles, and have done most to assist manufacturers to develop satisfactory machines. Considerable progress is still being made in some cities, notably Sheffield and Birmingham, but there is still a great field to be developed throughout the rest of great Britain. The system of dual control (from the driver's seat and from the side of the vehicle) introduced by Messrs. Garrett should be of great assistance in refuse collection work, as it allows the driver to assist in loading just as is done at present with horse-drawn vehicles.

Light electric vehicles have made no appreciable progress, and do not seem to have any prospect of success in face of the competition of numerous types of highly developed petrol cars which are available. Special applications such as invalid chairs are, of course, excepted, as for such purposes, battery propulsion is eminently suitable.

At the other end of the scale in the sphere of very heavy traction, the 6-wheel system enables the electric vehicle to compete with steam and petrol machines with good prospects of success, and the performance of the 10-ton machines built by the General Vehicle Company (Fig. 43) will be of great interest.

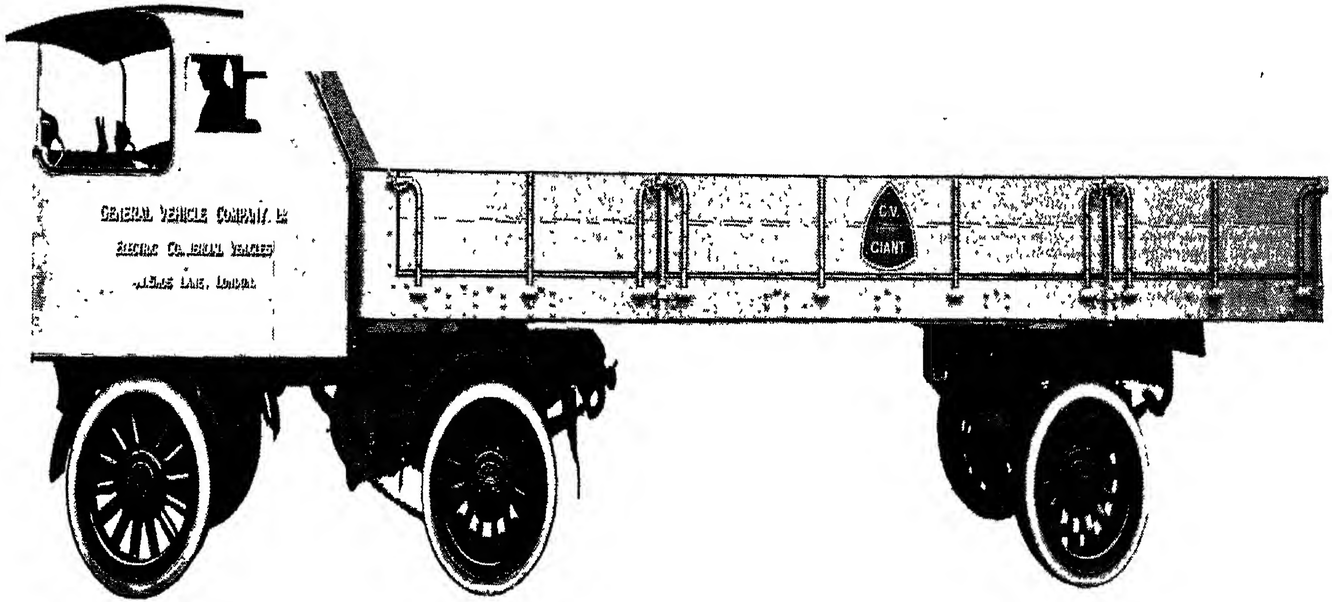

FIG. 43.—G.V. 10-Ton Electric Vehicle.

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